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Environmental Characterization for the RDS-4 Experiment in the Halifax Harbor Approaches and Emerald Basin

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14. ABSTRACT

The RDS-4 sea trial is the fourth in a series of trials sponsored by TTCP MAR TP-9 on the topic of Rapidly Deployable Systems. These trials are meant to study innovative designs of a new generation of economical, lightweight, and rapidly deployable sonar systems.

The RDS-4 trial is scheduled for September/October 2002, and will take place in the approaches of Halifax Harbor and Emerald Basin (Scotian Shelf). This report characterizes the acoustic and oceanographic environment of both areas.

The first site is adjacent to the coast at the entrance of Halifax Harbor. The very shallow-water site was chosen to maximize opportune target traffic near the RDS systems. The second site is located in water depths on the order of 100 m in Emerald Basin southeast of Halifax Harbor. This site will allow for a wide range of deployment depths for the experimental systems. It will also allow potential submarine targets to conduct submerged operations. Fishing activity is also more likely at this site.

15. SUBJECT TERMS

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ENVIRONMENTAL CHARACTERIZATION FOR THE RDS-4 EXPERIMENT IN THE HALIFAX HARBOR APPROACHES AND EMERALD BASIN

1. INTRODUCTION

The Rapidly Deployable Systems (RDS) sea trials sponsored by The Technical Cooperation Program Maritime Systems Group, Technical Panel 9 (TTCP-MAR TP9) are international collaborative experiments designed to evaluate acoustic systems that can be rapidly deployed and recovered in shallow water regions. Three sea trials have been completed:

RDS1: Canada (Western Bank, Scotian Shelf), June 2-19, 1997
RDS2: Australia (Timor Sea), October 29-November 12, 1998
RDS3: Italy (Adriatic Sea), October 6-17, 2000.

The fourth (RDS-4) trial is scheduled for September-October 2002 on the Scotian Shelf. This report presents an environmental characterization of the trial region compiled by RDS-4 participants from Canada and the United States.

Two sites have been chosen for RDS-4 (Fig. 1); Table 1 lists the coordinates. The first site is adjacent to the coast near Halifax Harbor. This very shallow-water site was chosen to maximize opportune target traffic near the arrays. It also allows for an array to be connected to a shore station via underwater cabling. The second site is in Emerald Basin, southeast of Halifax Harbor. This basin has a maximum depth of over 250 m, allowing for a wide range of deployment depths. The site was selected because it is well characterized from a geological point of view.

The Defence R&D Canada - Atlantic (DRDC Atlantic) compiled an initial set of environmental information and presented it at the TTCP MAR TP9 (Sensor Technology) meeting, October 15-19, 2001. That information is included in this report.

Table 1 — Operating Area Coordinates for the Two Proposed RDS-4 Experiment Sites

Trial Area 1 (Harbor Approach)	Trial Area 2 (Emerald Basin)
44° 28.50' N, 63° 32.00' W 44° 23.00' N, 63° 29.00' W 44° 28.50' N, 63° 9.00' W 44° 35.00' N, 63° 12.00' W	44° 12.00' N, 63° 27.00' W 43° 59.00' N, 63° 09.00' W 44° 11.00' N, 62° 53.00' W 44° 23.50' N, 63° 10.00' W

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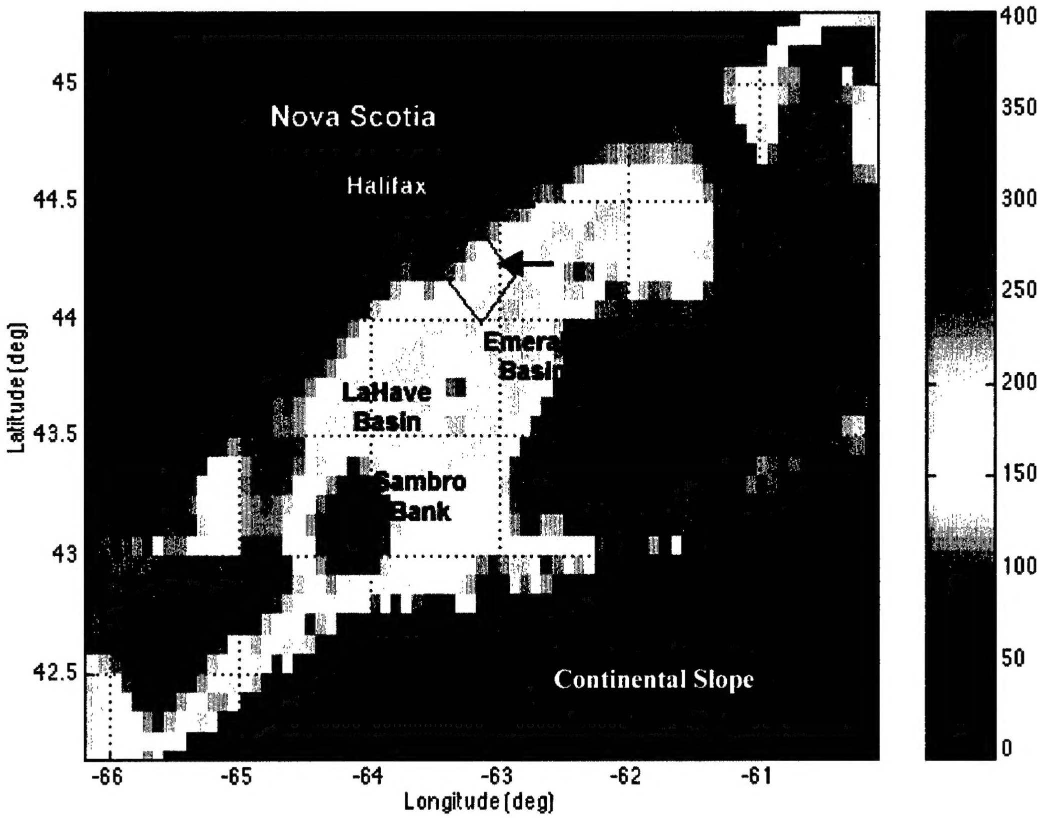

Fig. 1 — RDS-4 proposed experiment locations over DBDB-V bathymetry depicting significant topographic features

2. TOPOGRAPHY

The Scotian Shelf surrounds the Canadian province of Nova Scotia, extending seaward up to 200 nmi from the coast (Fig. 2). The dominant topographical features are two elliptical depressions or basins: the Emerald Basin and the LaHave Basin. Each has a maximum depth of over 250 m, deeper than the average shelf depth of 200 m. The slopes from the Sambro and Emerald banks to the basin floors vary between 0.1 deg and 0.3 deg except for the western side of the Emerald Basin where the slope locally reaches 1 deg or more (King 1965). A view of the proposed experimental sites with DBDB-V database bathymetry shows the significant topographical features in the trial area (Fig. 1). This combination of deep basins found nearshore and shallow banks offshore creates a natural barrier to exchanges between coastal and oceanic waters that has considerable effect on the oceanography of the Scotian Shelf.

3. OCEANOGRAPHY

This section describes the oceanographic environment of the Scotian Shelf and the range of variability that may be encountered. Historical data are summarized and used to select the sound speed environment expected during the sea test.

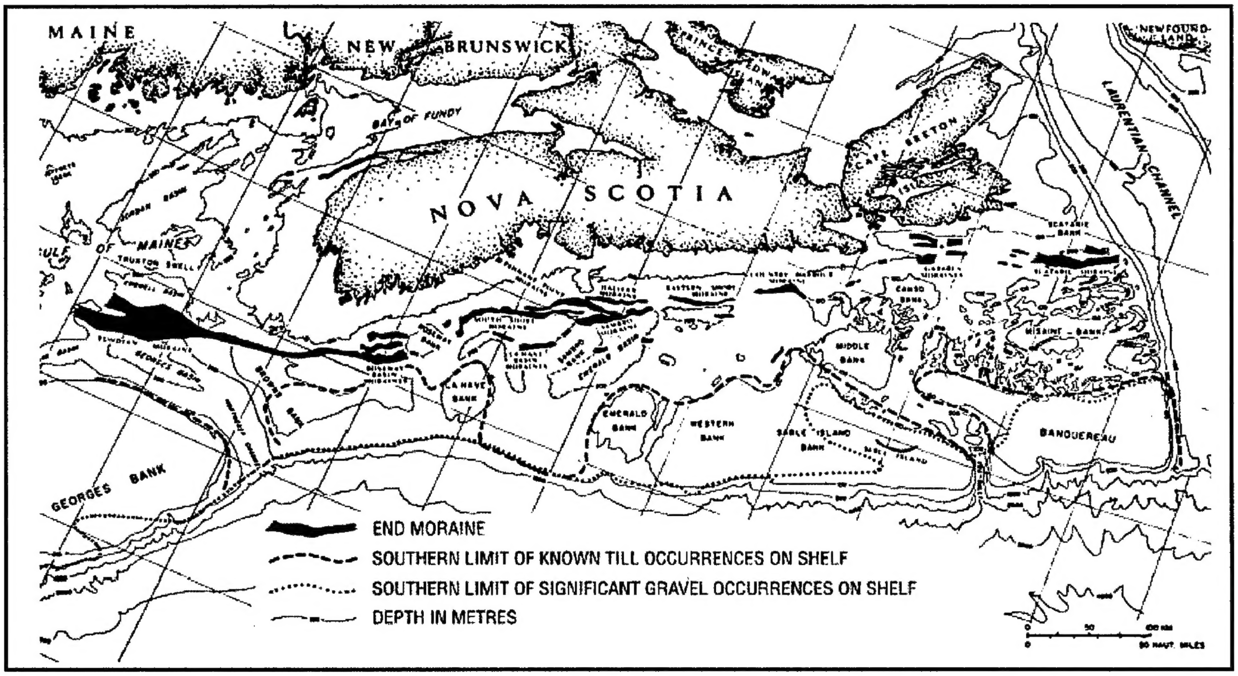

Fig. 2 — Topography of the Scotian Shelf (from http://museum.gov.ns.ca/mnh/nature/nhns/index.htm, T3.5)

3.1 Regional Water Masses

As shown in Fig. 3, the RDS-4 test area is near a region that is transitioning from coastal shelf water to slope water, to Gulf Stream water, and North Atlantic central water. The shelf is covered by a surface layer of relatively fresh, low-density coastal water known as Nova Scotia Current water. Near the outer edge of the continental shelf and separated by a sharp shelf edge front is a band of slope water. Beyond the slope water lies the Gulf Stream and then central Atlantic water. The three-dimensional structure is more complex with five water masses generally reported in the area south and east of Nova Scotia (Fig. 4):

1. Shelf or coastal water - The band along the coast that extends from near shore to approximately 100 nmi out to sea. Once thought to be mostly outflow from the Gulf of St. Lawrence (McLellan 1957; Sutcliffe el. al. 1976), isotope tracing has indicated the majority of this water originates as glacial melt and river runoff in the northern Labrador Sea (Chapman and Beardsley 1989). Large temperature gradients mark its boundary with the slope water.
2. Warm slope water – Warmer surface water of the slope that extends offshore to the Gulf Stream; it is a mixture of coastal water and Gulf Stream water. Typically found to a depth of 350 m, it generally lies above portions of the colder denser Labrador slope water and often intrudes under portions of shallow coastal water.
3. Cold or Labrador slope water – Colder subsurface water of the slope that underlies portions of coastal water and warm slope water; it is fed by the offshore Labrador Current mixing with North Atlantic central water.
4. Gulf Stream – Readily identified by low oxygen content and warm temperatures, the main axis of the Gulf Stream is well south of the planned experiment area.
5. North Atlantic Central Water – Occupies most of the deepwater area south of 41 deg N; it can be identified by salinity and oxygen anomalies.

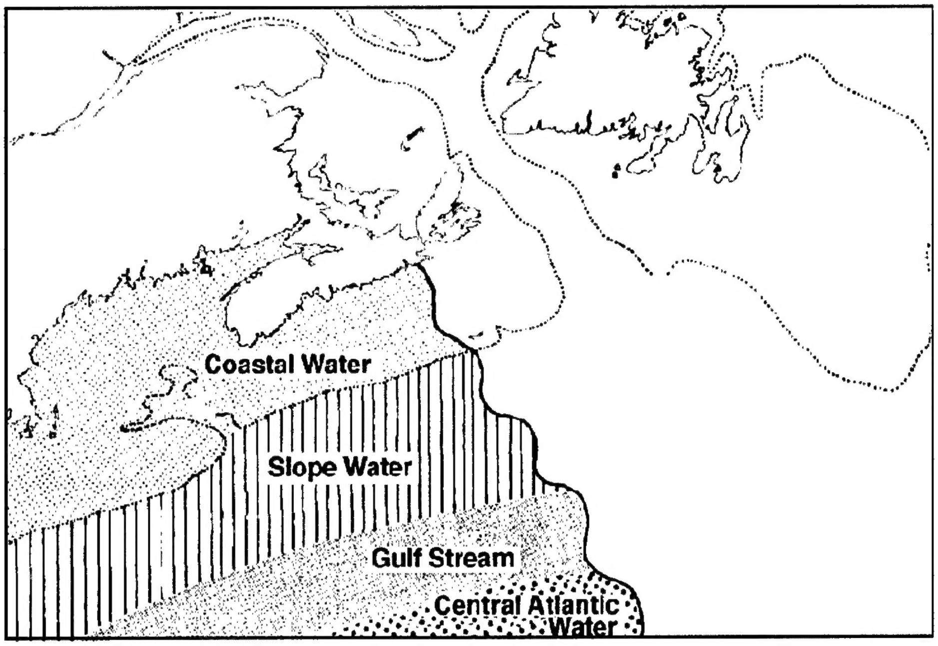

Fig. 3 — Approximate location of water masses moving offshore of Nova Scotia (from http://museum.gov.ns.ca/mnh/nature/nhns/index.htm, T6.2)

The RDS-4 experiment will be confined to the continental shelf where the dominant water mass is coastal shelf water with some intrusion of warm slope water. Water on the Scotian Shelf is described as having three layers:

1. a low-salinity upper layer that varies seasonally with temperatures (5 °C to 20 °C) and salinities (< 32 PSU);
2. a cold intermediate layer, up to 100 m thick (temperatures generally < 5 °C and salinities 32 to 34 PSU);
3. a warmer bottom layer usually between 90 and 200 m (temperatures above 5 °C and salinities > 33.5 PSU).

The upper two layers are considered coastal shelf water that results from Gulf of St. Lawrence outflow mixing with alongshore flow that originates off Greenland. The warmer, more saline bottom layer results from on-shelf excursions of warm slope water (Hachey 1937; McLellan and Trites 1951; and Osler 1994).

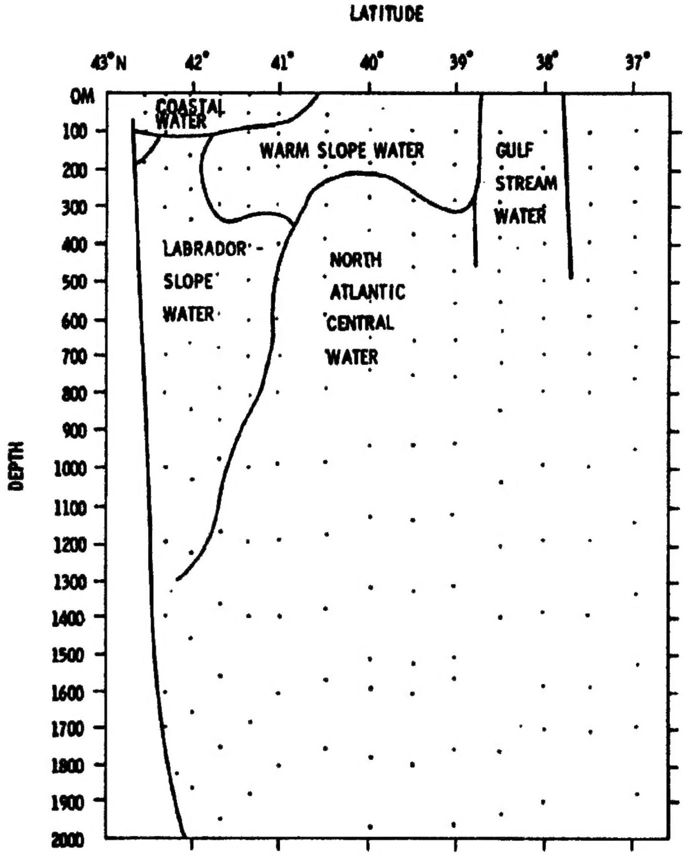

Fig. 4 — Schematic diagram showing approximate three-dimensional distribution of water masses in the slope water region south of Halifax (Gatien 1976)

3.2 Currents

The driving forces of circulation on the Scotian Shelf include (1) buoyancy fluxes, (2) surface wind stress, (3) tidal forces, and (4) large-scale circulation associated with adjacent deep-ocean gyres (Smith and Schwing 1991). The general circulation pattern in this region is illustrated in Fig. 5. The Scotian Shelf is covered by a surface layer of relatively fresh and low-density water called the Nova Scotia Current. It is considered part of an alongshore flow that originates along the southern coast of Greenland and continues to the Middle Atlantic Bight (Chapman and Beardsley 1989).

In an extensive review of mean circulation on the eastern Canadian Continental Shelf, Smith and Schwing (1991) summarized the dominant component of flow as beginning as glacial melt and river runoff in the northern Labrador Sea and following the coast generally south and west. The flow follows the continental shelf as the Labrador Current with the primary portion along the shelf break. It then diverges into the Inshore Labrador and Offshore Labrador near 48 deg N, with the predominant offshore branch (90%) following the outer edge of the Grand Banks while the inshore branch flows along the Newfoundland coast. Much of the Offshore Labrador turns eastward at the southern end of the Grand Banks, but some turns westward and becomes a deep component of the slope water off Nova Scotia. The Inshore Labrador Current then splits again with approximately 20 percent turning westward and entering the Gulf of St. Lawrence while the rest flows offshore. This coastal flow is reinforced by freshwater runoff in the Gulf of St. Lawrence where it flows onto the nearshore region of the Scotian Shelf. Here it flows westward to the Gulf of Maine. They report that inshore currents on the Scotian Shelf lie between 0.1 and 0.3 m/s.

In the test area, shelf water has a net southwest-to-south flow along the coast at speeds ranging from 0.05 to 0.2 m/s. Mean speed is fairly constant throughout the year with the greatest variability of the current seen in its changing width. Widest in the winter, this current narrows in summer and flows nearest to shore around Cape Sable.

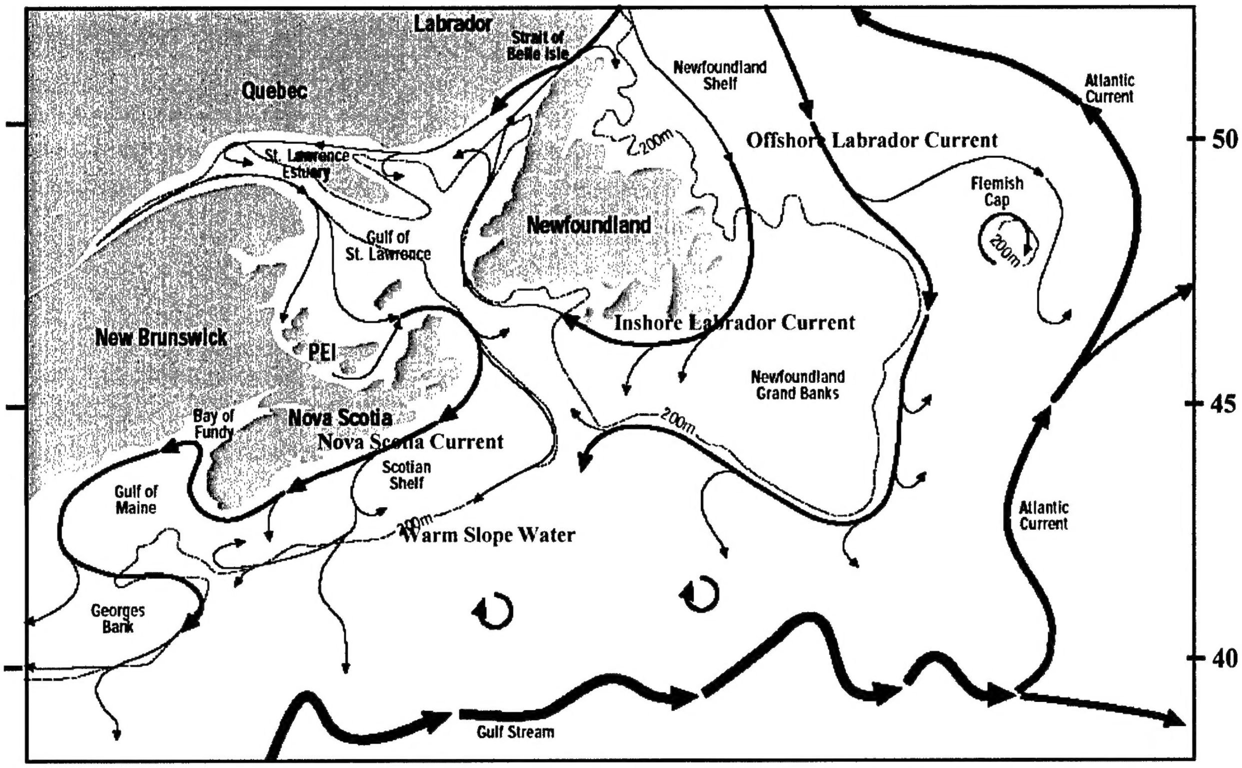

Fig. 5 — General surface circulation near Nova Scotia (http://museum.gov.ns.ca/mnh/nature/nhns/index.htm, T6.1)

South of the test area, slope water flows south to southwest and is constrained by both shelf water and the Gulf Stream. Mean speed is fairly constant throughout the year, ranging between 0.1 and 0.4 m/s. Further south of the test area, the Gulf Stream flows eastward across the North Atlantic. Surface current speeds of the Gulf Stream range from 0.05 to 3.4 m/s with means of 0.6 m/s between 60 deg W and 70 deg W. The position of the Gulf Stream varies widely, but is usually found within a fairly well-defined envelope, well south of the test area (Figs. 6 and 7). The shaded area shows the position of the Gulf Stream axis 50 percent of the time (NAVOCEANO 1985).

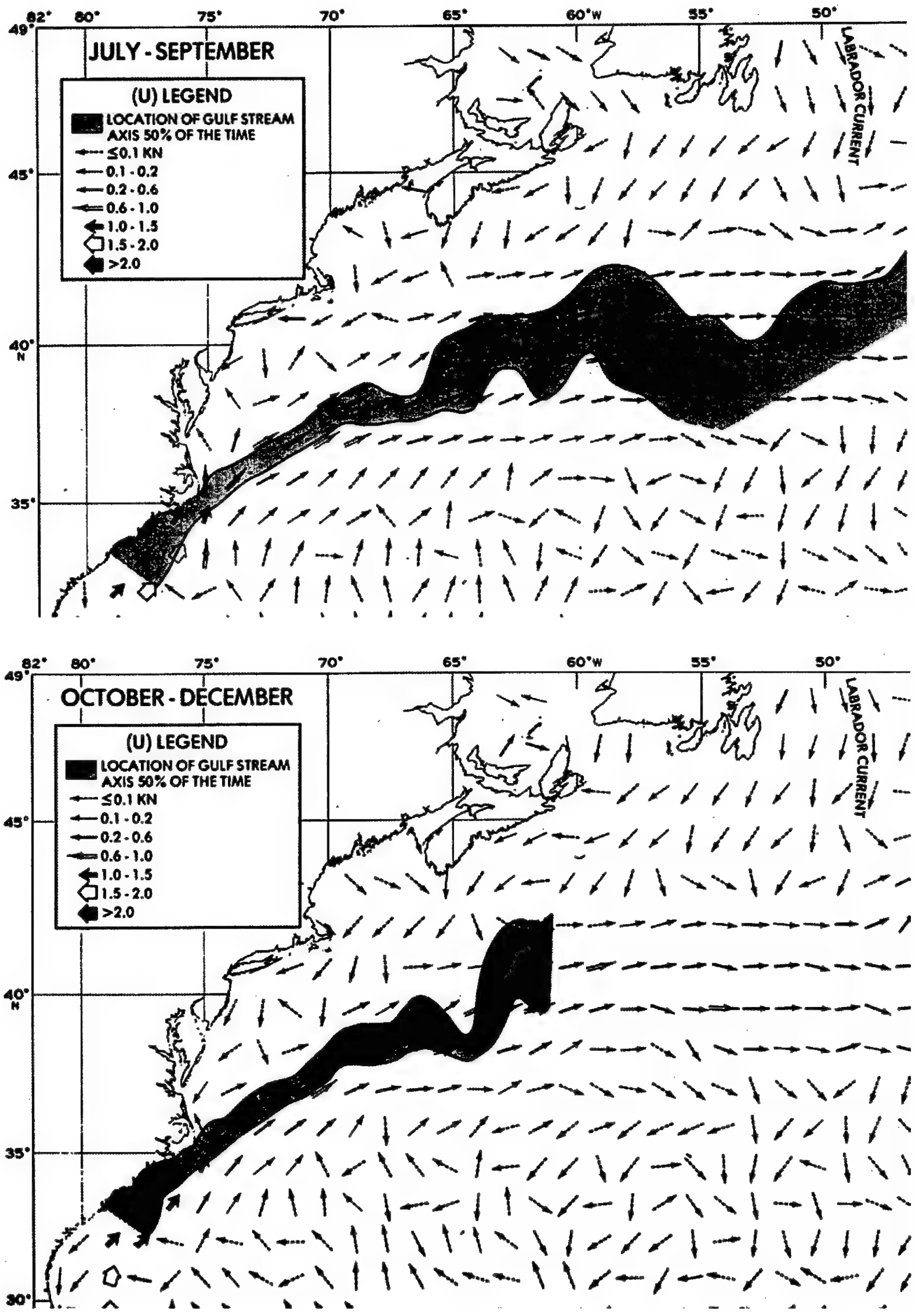

Fig. 6 — Path of the Gulf Stream during (top) July-September and (bottom) October-December (from unpublished report, Naval Oceanographic Office 1985)

Historical current data from moored sensors in the vicinity of the two RDS-4 sites were extracted from the Ocean Data Inventory database of the Ocean Science Division at the Bedford Institute of Oceanography, Nova Scotia, Canada for the month of September. The database is available online at http://www.mar.dfo-mpo.gc.ca/science/ocean/database/data_query.html. Statistics from these data include maximum speed (without regard to direction), mean speed, and vector-averaged direction (Tables 2 and 3). In these tables, sampling depth indicates the depth of the moored current meter. For Halifax Harbor

(Table 2), all 0-to-24-m depth data were collected in 1971 at the same location (44° 31.746' N, 63° 27.096' W), within 7 km of land, while the 95-m data were collected in 1968 at 44° 24.498 'N 63° 30.3' W, further away from land. In the Emerald Basin (Table 3), the 1967 and 1968 data were collected from sensors in the lower, deep-water area of the basin, while the 1991 data were collected from sensors positioned in the geographic middle of the basin. Historical nearshore currents were small throughout the water column during September (a mean of less than 0.1 m/s and peak speeds of less than 0.3 m/s). Mean direction was predominantly toward the southwest (exception was the deepest reading collected from a different year and further offshore indicating flow to the east-northeast). Historical Emerald Basin currents were also small throughout the water column during September (means ≤ 0.1 m/s). Peak flow did reach nearly 0.4 m/s and mean direction was more variable. However, flow was predominantly southerly (150 to 200 deg true north (° T)). Additional current statistics for the Scotian Shelf are available in Gregory and Smith (1988).

Moored current meter data and a barotropic tidal circulation model were used jointly to develop statistics for the entire shelf and to analyze the tidal variability. As a result, variance of the tidal current has been described in terms of three semi-diurnal and two diurnal constituents (Gregory 1988). The largest tidal currents on the shelf are at the entrance to the Bay of Fundy where they can exceed 4 m/s. Magnitudes of tides at the entrance to the Bay of Fundy are predicted to be from 1 to 4 knots during RDS-4. The directions are 032 True and 212 True. These numbers are for Grand Manan Channel, which lies between Grand Manan Island and the coast of New Brunswick and Maine. However, at the RDS-4 trial sites, the tidal current variability is expected to be low (< 0.1 m/s).

Table 2 — Currents in the Vicinity of the Entrance to Halifax Harbor (from: http://www.mar.dfo-mpo.gc.ca/science/ocean/database/data_query.html)

Year	Sampling Depth (m)	Max Speed (m/s)	Mean Speed (m/s)	Mean Dir (°T)
1971	0	0.237	0.112	232
1971	3	0.262	0.075	236
1971	14	0.216	0.076	226
1971	24	0.195	0.054	286
1968	95	0.139	0.035	67

Table 3 — Currents in the Emerald Basin (from: http://www.mar.dfo-mpo.gc.ca/science/ocean/database/data_query.html)

Sampling Depth (m)		Max Speed (m/s)		Mean Speed (m/s)		Mean Dir (°T)	
Lower Deep Basin							
1967	1968	1967	1968	1967	1968	1967	1968
20		0.386		0.013		308	
50	50	0.334	0.175	0.104	0.019	196	155
	95		0.170		0.053		150
250	250	0.242	0.195	0.004	0.017	167	89
Mid Basin							
1991		1991		1991		1991	
230		0.194-203		0.013-018		205-198	
250		0.174		0.020		187	

3.3 Temperature and Salinity

Temperature and salinity vary with depth and season because of summer heating and winter cooling of the surface waters and changes in circulation patterns. The effect of summer warming as first described by McLellan and Trites (1951) is observed in three ways: (1) development of a strong temperature stratification; (2) deepening of the 'upper' layer; and (3) dissipation of the 'intermediate' layer. The greatest extent of this is reached in late summer and early fall with an almost isothermal surface layer with temperatures of 10° to 11 °C lying over a much colder intermediate layer. Winter chilling lowers surface temperatures as much as 6 °C and makes surface temperatures lower than the intermediate layer; prior to this chilling, the intermediate layer was the region of temperature minimum. Long-term changes in temperature and salinity characteristics appear to be caused by subsurface waters from the continental slope moving onto the shelf and flooding the deep inner basins (Petrie and Drinkwater 1993).

Historical data on the temperature and salinity around Nova Scotia show that during winter, the shelf water has a two-layer structure with colder, fresher water near the surface overlaying warmer, more saline waters. By contrast, in summer, the near-surface waters warm substantially creating a three-layer structure with a warm surface layer, a cold intermediate-depth layer, and a warm bottom layer (see Section 3.1). These data are separated into hydrographic subareas and made available by the Department of Canadian Fisheries and Oceans at http://www.mar.dfo-mpo.gc.ca/science/ocean/scotia/ssmap.html. Subareas 10, 11, 12, 13, 14, and 15 include the RDS-4 test area and nearby waters (Fig. 7). Two locations (13 and 14) are coastal areas, two locations (12 and 15) are basin areas and two locations (10 and 11) are banks beyond the Emerald Basin.

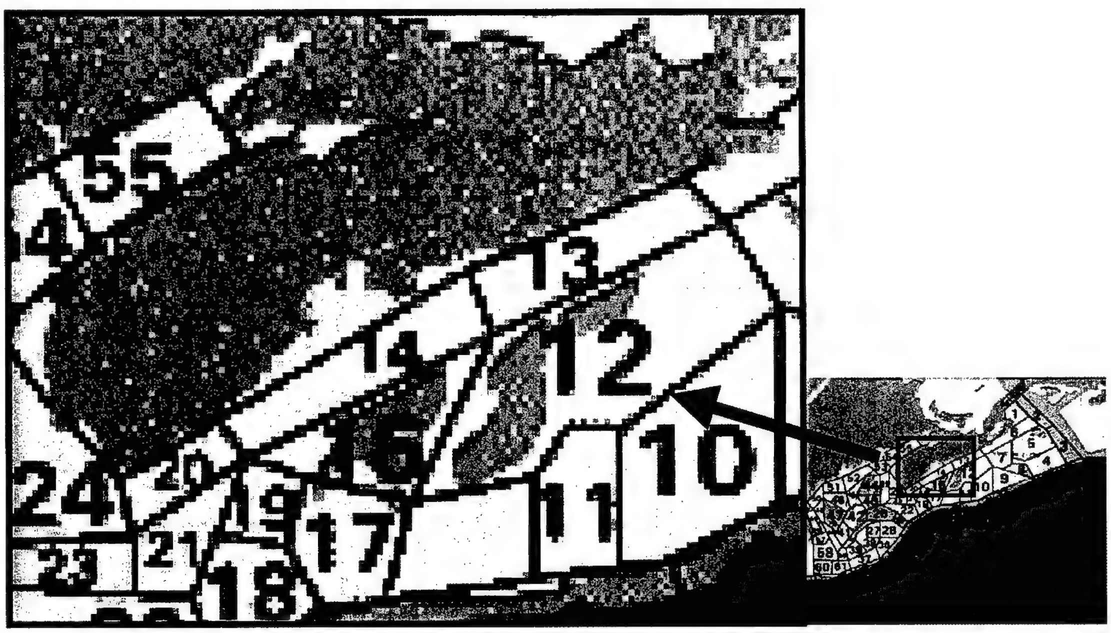

Fig. 7 — Locations of database subareas (from http://www.mar.dfo-mpo.gc.ca/science/ocean/scotia/ssmap.html)

The described temperature and salinity structure with season can be seen in Fig. 8. In the six areas of interest, water column temperature minimums occur in surface waters from January to May and in the intermediate layer from May to December. The highest sea-surface temperature and greatest stratification in the water column occurs from August to September, creating a sound channel of approximately 50 to 100 m for coastal locations (subareas 13 and 14) and approximately 50 to 80 m for basin areas (subareas 12 and 15). Near-bottom temperatures range 5 °C to 9 °C and appear fairly stable year round; the 5 °C contour occurs at approximately 125 to 140 m for nearshore areas and at approximately 75 to 100 m for the Emerald and LaHave Basins. Bottom salinity appears fairly stable throughout the year in the basin areas, with the lowest surface salinity occurring during summer and fall of all six areas. The bottom layer

in the basins comes from relatively dense water from the continental slope moving onto the shelf and flooding the inner basins.

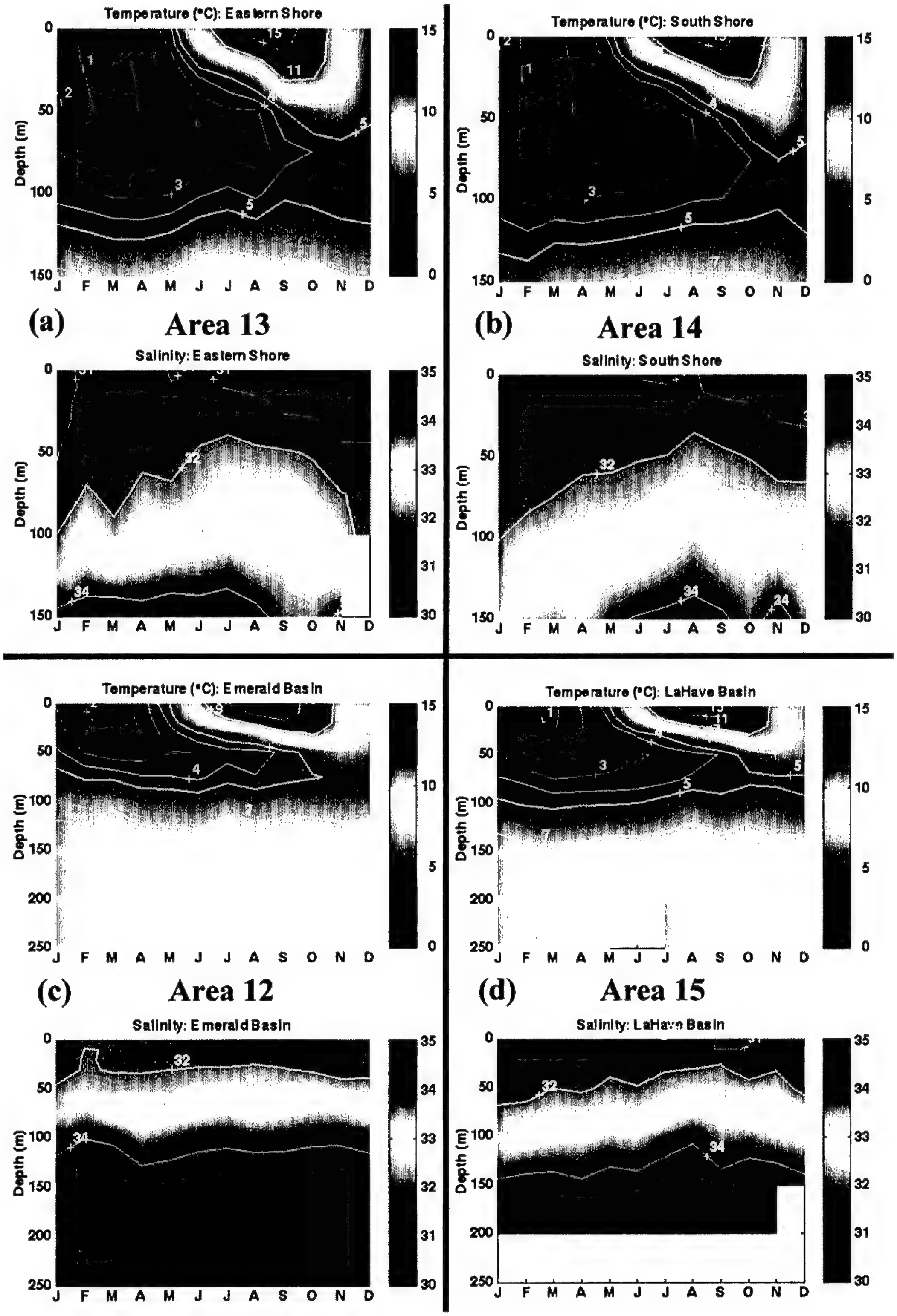

Fig. 8 — Seasonal temperature and salinity with depth in nearshore Scotian shelf waters: (a) chart area 13 (b) chart area 14 and basin areas of the Scotian shelf: (c) chart area 12 (d) chart area 15 (from www.mar.dfompo.gc.ca/science/ocean/ scotia/ssmap.html)

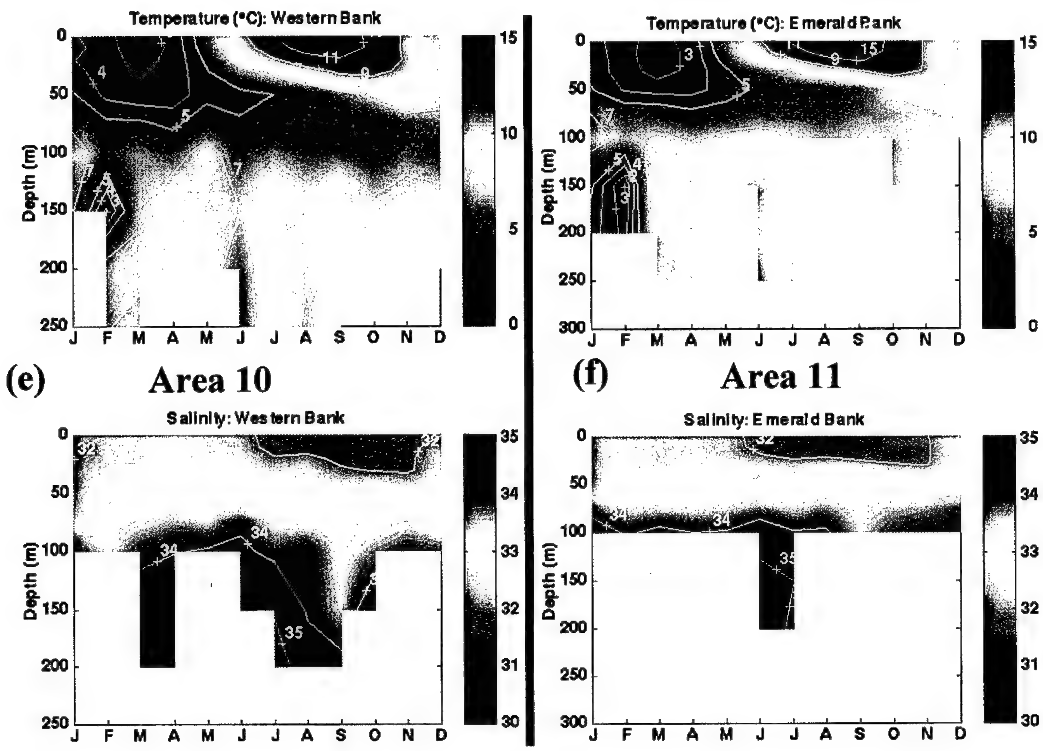

Fig. 8 (cont). — Seasonal temperature and salinity with depth in outer bank Scotian shelf waters: (e) Western Bank, chart area 10 and (f) Emerald Bank, chart area 11 (from www.mar.dfo-mpo.gc.ca/science/ocean/scotia/ssmap.html)

Table 4 depicts the seasonal extremes in waters surrounding the test area. In February, shelf water has a two-layer structure where the upper-layer temperatures are near 0 °C near shore, warmer offshore over the basins, and gradually warming several degrees toward the outer bank areas. Similarly, salinities are lowest near shore and increase gradually offshore. Throughout the area in February, the coldest, freshest water is in the upper layer while the warmest, most saline water is in the deep layer. By contrast, in August, there is a three-layer structure where upper-layer temperatures are about 15 °C near shore and increase seaward to around 19 °C over the outer bank areas. Here, too, salinities are lowest near shore and increase gradually seaward. Throughout the area in August, the warmest, freshest water is in the surface layer while the coldest water is in the intermediate layer, and the densest, most saline water is in the bottom layer.

Table 4 — Average Temperature and Salinity at Seasonal Extremes for February and August (from http://museum.gov.ns.ca/mnh/nature/nhns/index.htm)

Region Name	Temperature (°C)						Salinity (ppt)					
	0 m		30 m		100 m		0 m		30 m		100 m	
	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug
Eastern Shore	0.7	15.4	1.0	4.8	3.8	3.6	31.2	30.7	31.3	32.0	32.9	33.1
South Shore	0.6	14.8	0.5	4.1	2.8	3.8	31.3	31.0	31.4	32.0	32.5	33.2
Emerald Basin	2.4	17.7	2.9	5.3	7.1	5.3	32.1	30.9	32.3	32.4	34.2	33.7
LaHave Basin	1.1	15.7	1.5	4.9	3.8	4.6	31.2	31.0	31.4	32.3	33.1	33.5
Emerald Bank	3.4	19.1	3.7	8.1	8.1	8.9	32.4	31.2	32.5	33.9	34.4	34.7
Western Bank	3.4	18.9	3.5	8.6	7.5	7.0	32.3	31.7	32.4	32.6	34.0	34.2

September/October is a transitional period; plotted temperature and salinity statistics display the temporal variability encountered in the waters around the test area (Fig. 9). The mean monthly values with ± 1 standard deviation along with monthly minimum and maximum values indicate that the September/October period has some of the highest sea surface temperatures with greatest variability of the year; values are read from the plot. Sea-surface temperatures average about 15 °C but range from approximately 8° to 20 °C; salinities average about 31 PSU but range approximately from 29.2 to 33.0 PSU during this period. At 150 m depth, temperatures average about 7 °C but range approximately from 2° to 12 °C; salinities average about 34 PSU but range approximately from 33.0 to 35.1 PSU. Tabulated temperature and salinity along with the resultant sound speeds for September/October are presented in Section 3.4.

Temperature and salinity from representative days of winter, spring, summer, and fall show the seasonal pattern of horizontal variability in the region (Figs. 10 and 11). Throughout the year, warmer more saline bottom waters occupy the deeper basin areas of the shelf and down the slope. Both bottom temperature and salinity are fairly stable throughout the year with warmer and more saline bottom waters occupying the deeper basin areas of the shelf and down the slope. The bottom layer in the deep basin areas is formed by relatively dense warmer water from the continental slope moving onto the shelf and flooding the inner basins.

Surface waters show much greater variability of temperature and salinity. In addition to the obvious effects of summer heating and winter cooling, the horizontal pattern of surface temperature and salinity also appears to reflect the horizontal pattern of bottom temperature and salinity. Petrie and Drinkwater (1993) suggest that the deep shelf water influences long-term changes in the upper layers of shelf water through gradual mixing.

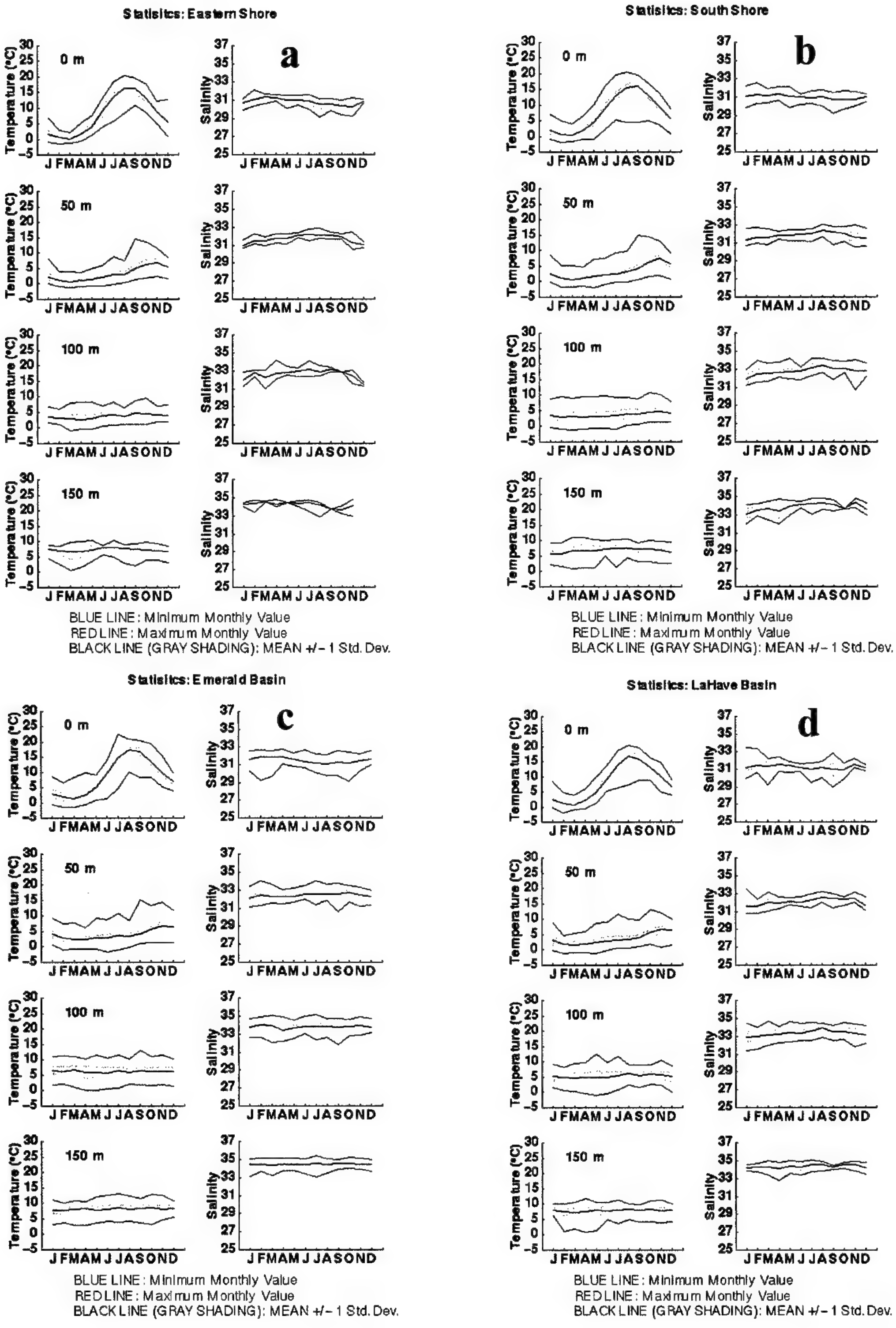

Fig. 9 — Monthly mean, minimum, and maximum temperature and salinity with depth in nearshore Scotian Shelf waters: (a) chart area 13 (b) chart area 14 and basin areas of the Scotian Shelf: (c) chart area 12 (d) chart area 15 (from http://www.mar.dfo-mpo.gc.ca/science/ocean/scotia/ssmap.html)

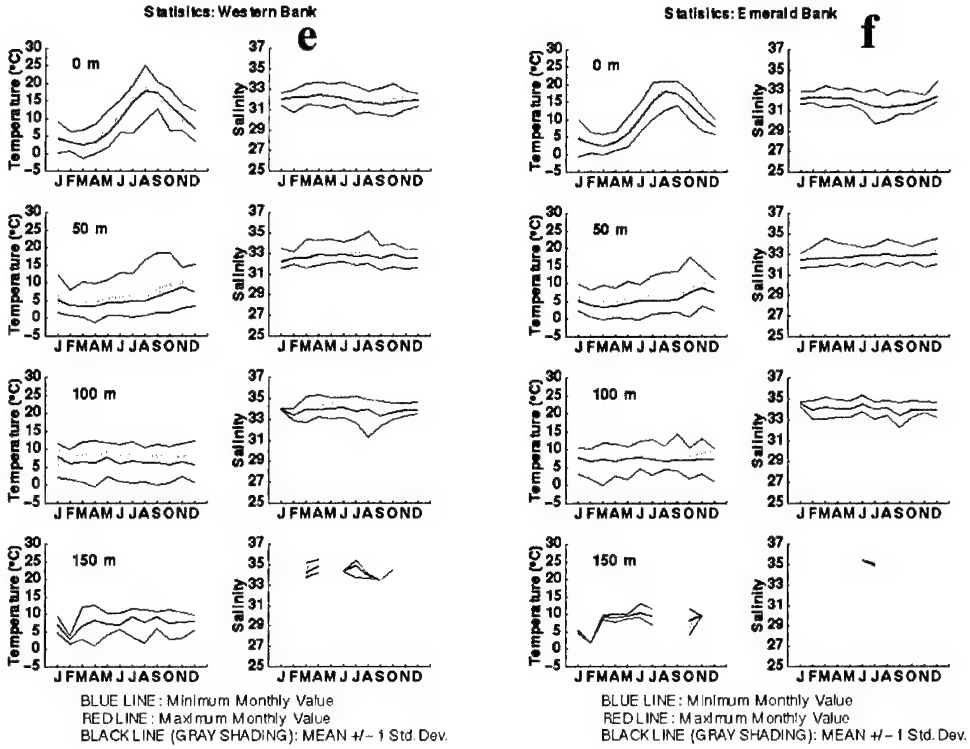

Fig. 9 (cont.) — Monthly mean, minimum, and maximum temperature and salinity with depth in outer bank areas of the Scotian Shelf: (e) Western Bank, chart area 10 (f) Emerald Bank, chart area 11 (website www.mar.dfo-mpo.gc.ca/science/ ocean/ scotia/ssmap.html)

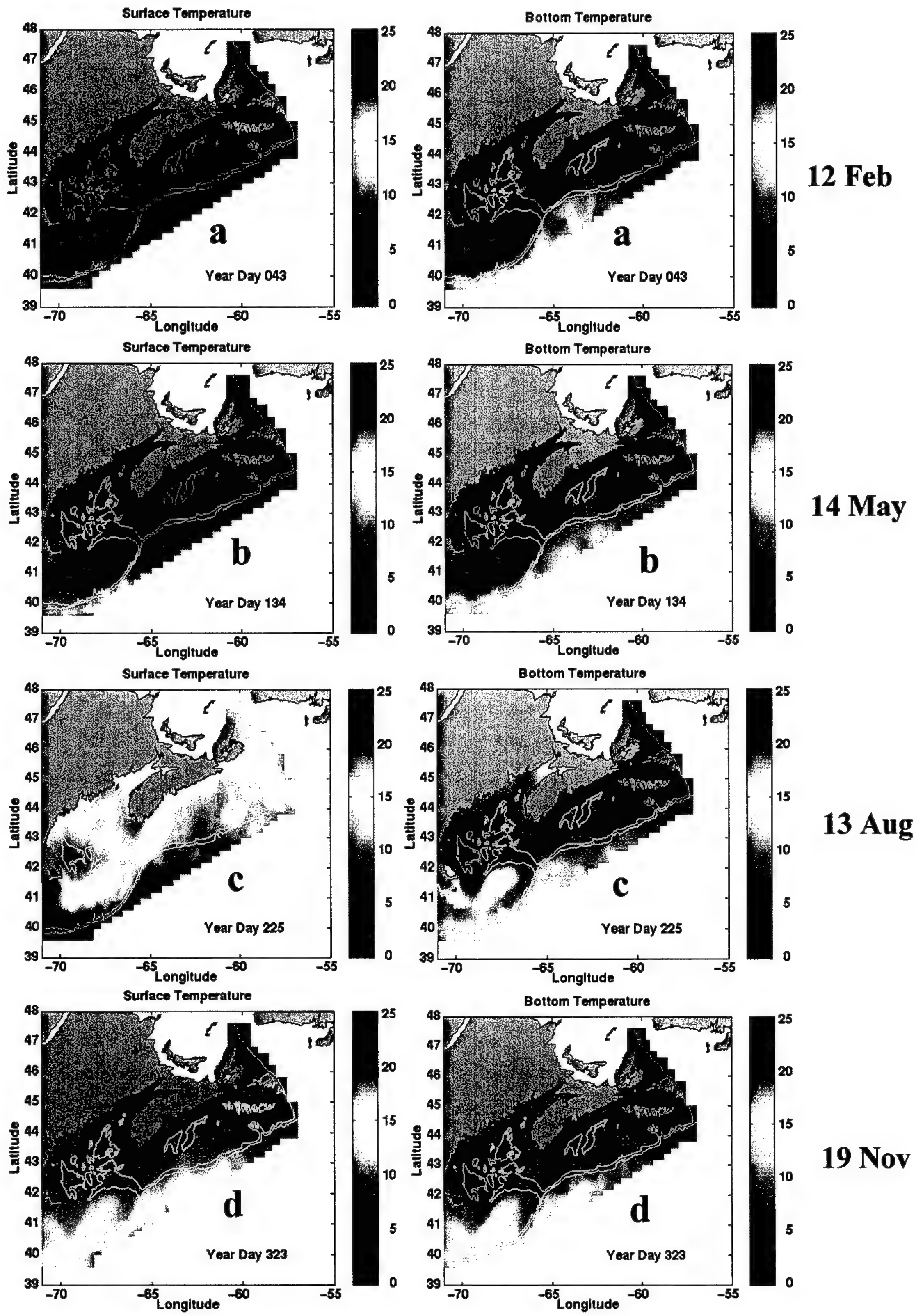

Fig. 10 — Regional surface and bottom temperatures for representative days during: (a) winter (b) spring, (c) summer, and (d) fall (from www.mar.dfo-mpo.gc.ca/science/ocean/scotia/ssmap.html)

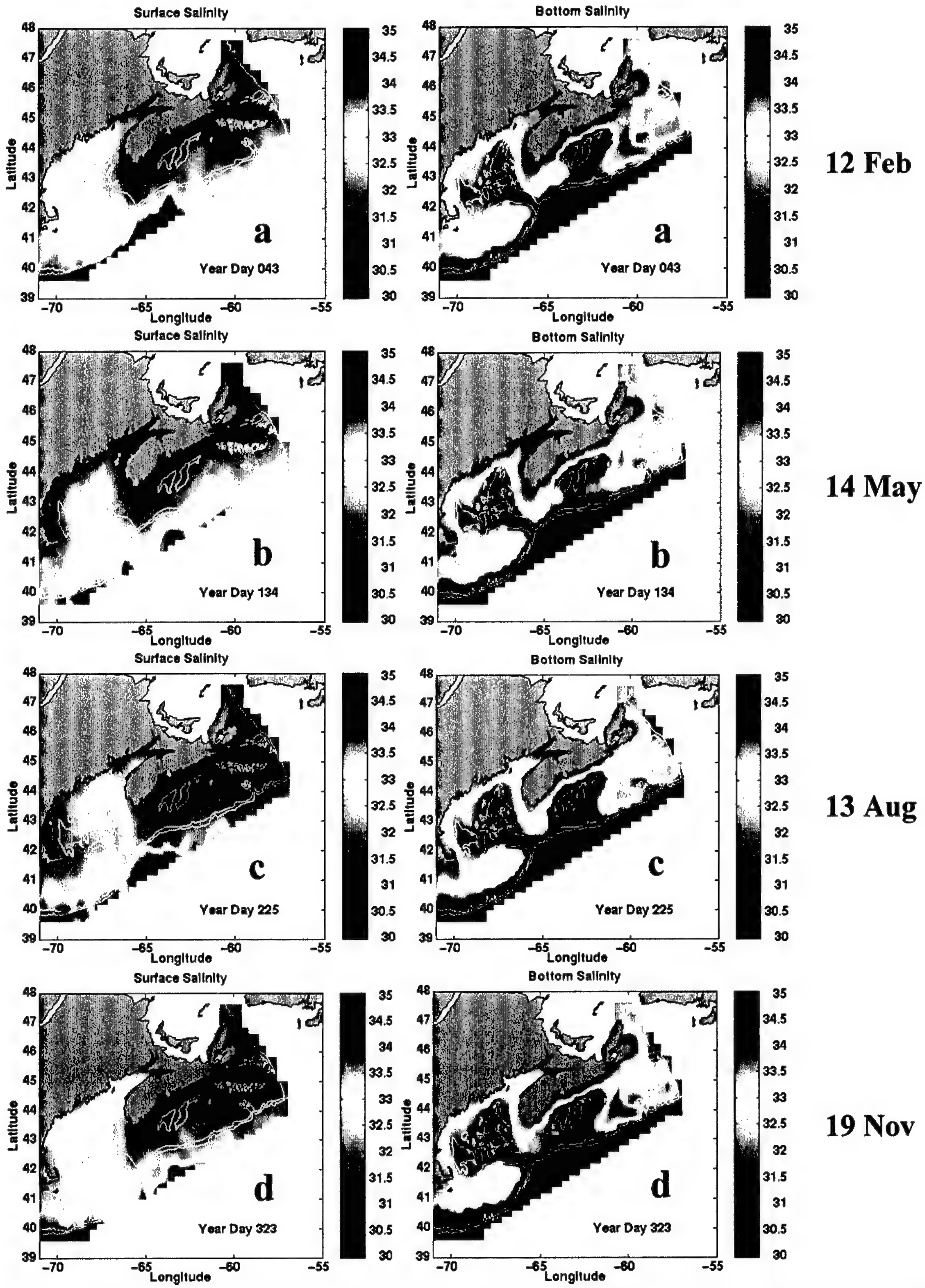

Fig. 11 — Regional surface and bottom salinities for representative days during: (a) winter (b) spring, (c) summer, and (d) fall (from www.mar.dfo-mpo.gc.ca/science/ocean/scotia/ssmap.html)

3.4 Sound Speed Profiles

As described in Section 3.3 on temperature and salinity, solar heating creates a three-layered water column over much of the shelf during the summer and fall. These increased sea surface temperatures peak in August/September. As a result, a shallow sound channel could exist during the time of the RDS-4 test at a depth of approximately 50 to 100 m. At shallow locations on the shelf, it appears there will be no warm bottom layer and a strongly downward refracting profile is expected.

Individual historical profiles of temperature, salinity, and sound speed for the September and October time frame were extracted from the Master Observation Oceanographic Data Set (MOODS) for an area defined by 43.5 deg to 44.7 deg N and 62.5 deg to 64 deg W (NAVOCEANO 1991). A composite of these profiles is given in Fig. 12a. The MOODS historical sound speed profiles indicate high variability in the area with individual profile shapes representing oceanographic conditions ranging from a shallow, low salinity coastal waters to complex shelf/slope water interactions. Cluster analysis of these historical profiles indicated that they could be loosely grouped into four offshore regions shown in Fig. 12b. Profiles plotted, according to these groupings, depict a sound speed environment that changes seaward. The profiles collected in nearshore area 1 are downwardly refracting with insufficient depth for the formation of a shallow sound speed duct. Profiles in area 2 show increased sound speed near the bottom, but also lack sufficient depth for the formation of a near surface duct. Profiles in deeper areas 3 and 4 have a shallow sound channel at approximately 50 to 100 m (Fig. 13).

Statistical analysis of the extracted historical profiles for each area selects an actual profile that is typical of the composite average, along with a mean, standard deviation, and an extreme envelope of maximum and minimum values. Figure 14 shows the actual profile closest to the mean, the mean, minimum, and maximum for each four areas. Table 5 lists these profile values.

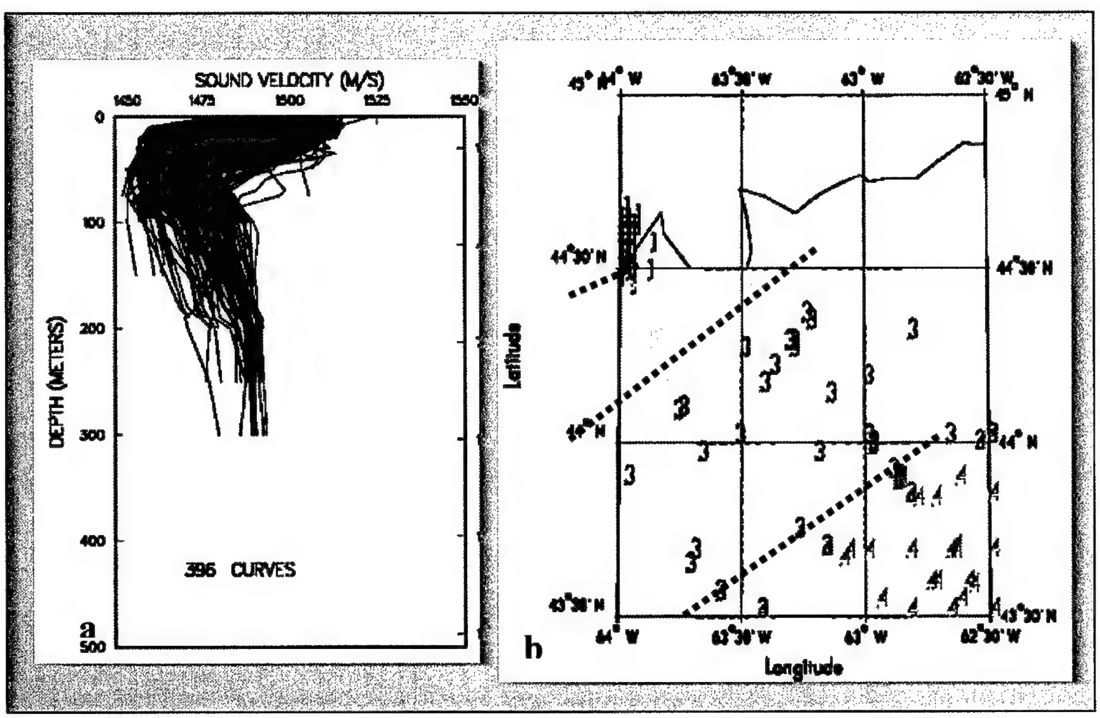

Fig. 12 — (a) Historical profiles extracted from MOODS for September and October and (b) profile locations by region

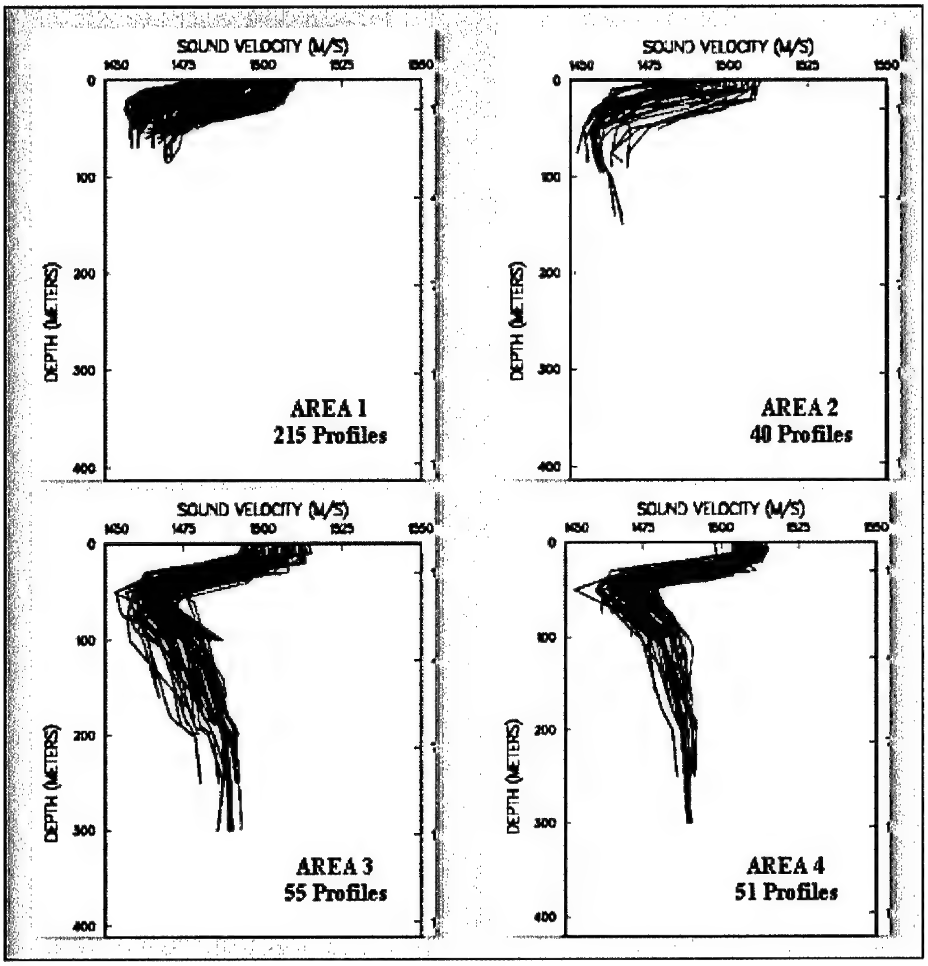

Fig. 13 — Historical profiles separated by location according to the areas shown in Fig. 12

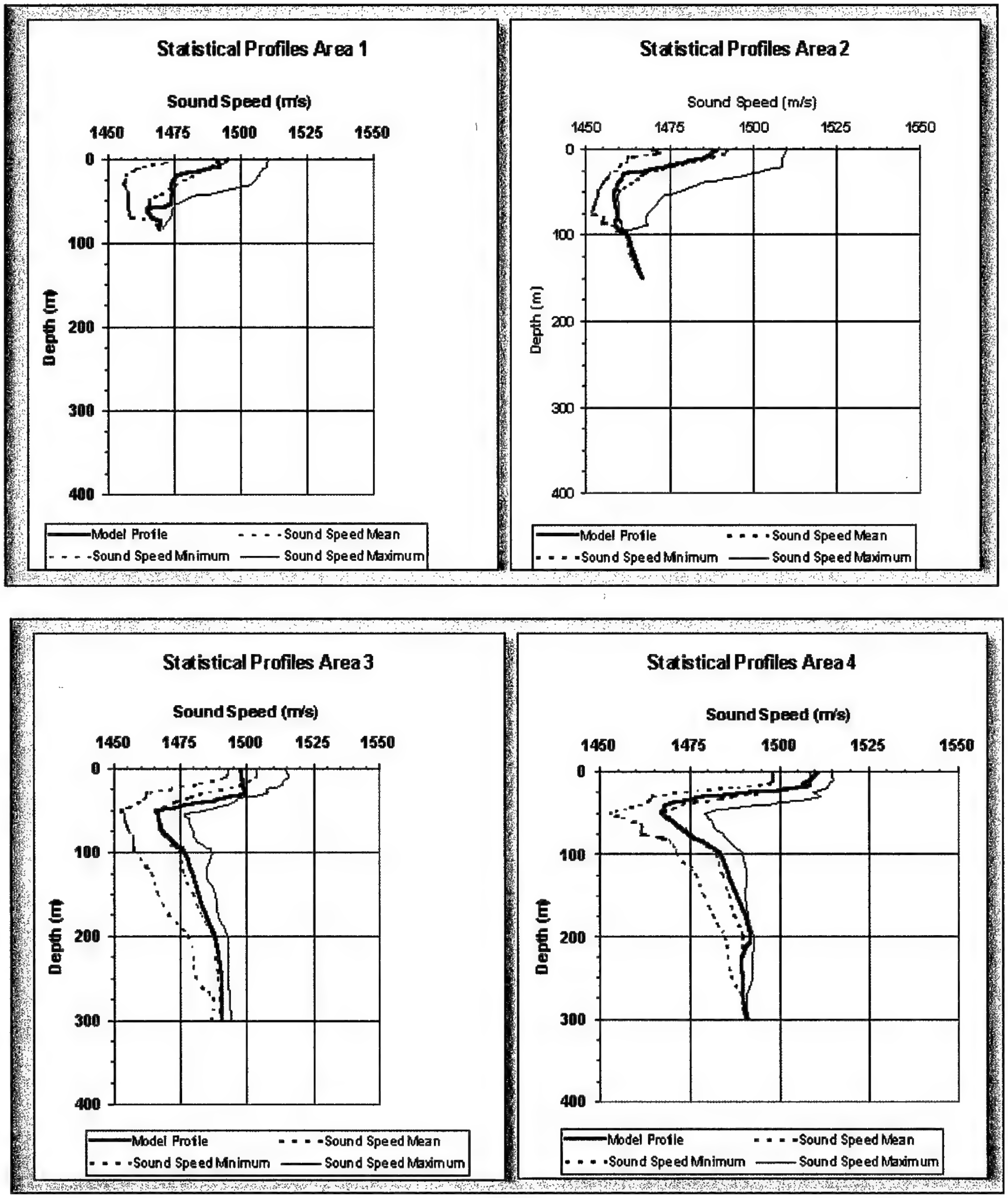

Fig. 14 — Representative, mean, and envelope minimum and maximum profiles according to the areas shown in Fig. 12

Table 5 — MOODS Sound Speed Profiles and Statistics for the Four Areas

Area 1

Depth (m)	Typical (m/s)	Mean (m/s)	Minimum (m/s)	Maximum (m/s)	Std Dev (m/s)
0	1491.6	1495.4	1476.2	1510.6	8.5
5	1491.8	1493.7	1471.4	1509.9	9.6
10	1491.9	1488.6	1462.7	1509.4	13.4
15	1484.5	1485.5	1459.9	1507.9	14.4
20	1476.5	1482.5	1457	1506.9	15.5
25	1475.3	1479.6	1456.9	1505.2	14.6
30	1474.1	1476.5	1456.2	1503.5	13.9
35	1474.1	1474.1	1456.9	1497	11.6
40	1474.2	1471.1	1457.6	1490.1	9.5
45	1474	1468.6	1457.7	1482.3	7.3
50	1473.8	1465.8	1457.7	1479	6.2
55	1473.6	1465.8	1457.9	1475.1	5.4
60	1465	1465	1457.8	1474.1	5.4
65	1465.7	1465.7	1458.5	1473.8	5.4
70	1466.8	1466.8	1458.6	1473.4	5
75	1470.2	1470.2	1469	1472.5	1.2
80	1470	1470	1468.7	1471.4	0.9
85	1469.9	1469.9	1469.4	1470.3	0.5

Area 2

Depth (m)	Typical (m/s)	Mean (m/s)	Minimum (m/s)	Maximum (m/s)	Std Dev (m/s)
0	1489.4	1492.7	1470.1	1510.1	9.7
5	1487.5	1491.7	1471.8	1509.5	10.3
10	1485.6	1488.4	1462.8	1508.8	13.3
15	1480	1482.7	1462.6	1508.6	12.9
20	1474.2	1476.6	1460.6	1508.4	14
25	1468	1471.6	1459.4	1502.6	12.8
30	1461.6	1467.6	1457.4	1499.1	11.5
35	1460.9	1466.1	1456.6	1492.1	9.8
40	1460.1	1464.1	1455.7	1484.7	8.1
45	1459.3	1461.9	1454.8	1481.3	6.6
50	1458.6	1460.2	1453.9	1477.8	5.9
55	1458.7	1459.8	1453.8	1473.3	5.1
60	1459	1459.6	1453.3	1472	4.7
65	1459.1	1459.9	1452.9	1470.8	4.7
70	1459.3	1459.7	1452.5	1469.5	4.4
75	1459.5	1459.4	1452.1	1468.4	4
80	1459.3	1459.9	1455.4	1468.1	3.2
85	1459.1	1460.5	1455.3	1468.1	3.4
90	1458.9	1460.8	1458.7	1468.1	2.6
95	1461.1	1461.1	1459.5	1461.9	0.9
100	1462.6	1462.6	1462.2	1462.9	0.4
125	1464.5	1464.5	1463.6	1465.2	0.9
150	1467	1467	1467	1467	0.3

Table 5 — MOODS Sound Speed Profiles and Statistics for the Four Areas, cont'd

Area 3

Depth (m)	Typical (m/s)	Mean (m/s)	Minimum (m/s)	Maximum (m/s)	Std Dev (m/s)
0	1498	1504.1	1493.1	1514.7	6.2
5	1498.2	1504	1493.1	1514.9	6.5
10	1498.4	1503.9	1492.3	1515.5	6.8
15	1498.6	1501.3	1487.2	1513.4	6.4
20	1498.8	1498.5	1480.8	1513.5	8.1
25	1499	1491.2	1472	1507.9	8.8
30	1499.2	1483.5	1462.7	1507.8	12.4
35	1491.7	1478.6	1462	1497.3	10.5
40	1483.8	1473.5	1459.8	1495.1	9
45	1475.4	1469.6	1456.7	1489.3	7
50	1466.5	1465.9	1453	1483.1	5.8
55	1466.8	1466.3	1453.9	1476.6	4.9
60	1467.2	1466.6	1454.2	1478.2	4.7
65	1467.5	1466.9	1454.5	1478.6	4.7
70	1467.9	1467.4	1454.9	1479	5.1
75	1468.2	1467.9	1455.8	1479.5	5.6
80	1470	1469.2	1457.2	1479.9	5.7
85	1471.8	1470.6	1457.3	1480.8	6
90	1473.5	1472	1457.5	1482.9	6.2
95	1475.3	1473.4	1457.6	1485	6.5
100	1477	1474.7	1457.8	1487.1	6.7
125	1479.6	1476.6	1464.4	1484.6	5.7
150	1482.1	1480	1466.7	1488.2	5.4
175	1484.6	1482.8	1470.7	1489.2	5
200	1488.4	1487.5	1477.9	1492.7	4.1
225	1489.5	1488.6	1479.9	1492.5	2.8
250	1490.6	1489.5	1481	1493.2	2.7
275	1490.6	1490.2	1487.3	1493.6	1.7
300	1490.5	1490.3	1486.5	1494	2.1

Area 4

Depth (m)	Typical (m/s)	Mean (m/s)	Minimum (m/s)	Maximum (m/s)	Std Dev (m/s)
0	1511	1509.3	1498	1514.7	3.3
5	1509.8	1509	1498.2	1514.9	3.3
10	1508.8	1508.7	1498.4	1515.1	3.3
15	1508.8	1507.2	1497.5	1514	3.9
20	1506.2	1505.4	1487	1513.5	6.4
25	1492.1	1497	1474.4	1509.4	8.3
30	1478.5	1487.2	1464.6	1511.4	11.9
35	1473.3	1480.4	1463.8	1503.8	9.7
40	1468.7	1473.5	1461.8	1496.4	8.3
45	1467.7	1470.6	1457.5	1485.1	6.2
50	1467.1	1468	1453	1479.4	5.5
55	1468.6	1469.4	1456.2	1480.1	5.3
60	1470.1	1470.8	1459.4	1480.8	5.2

Table 5 — MOODS Sound Speed Profiles and Statistics for the Four Areas, cont'd

Area 4

Depth (m)	**Typical (m/s)**	**Mean (m/s)**	**Minimum (m/s)**	**Maximum (m/s)**	**Std Dev (m/s)**
75	1474.6	1475.2	1461.6	1484.2	5.6
80	1476.5	1476.9	1467.8	1485	4.9
85	1478.4	1478.4	1469.2	1485.8	4.6
90	1480.2	1480	1470.5	1487	4.3
95	1482.1	1481.4	1471.2	1488.3	4.3
100	1483.7	1482.5	1471.2	1489.5	4.2
125	1486	1484.1	1476.7	1490.7	3.5
150	1488.3	1486	1478.8	1490.2	3.1
175	1490.5	1487.6	1481.4	1491.2	2.5
200	1491.9	1489.8	1484.8	1492.7	2.2
225	1489.5	1489.5	1485.7	1492.3	1.7
250	1490	1490	1486.7	1492.4	1.5
275	1490	1490	1489.5	1490.6	0.8
300	1490.4	1490.4	1489.9	1491.3	0.8

Monthly averages of temperature and salinity for each region described in Section 3.3 are tabulated along with a resultant sound speed calculated using Wilson's equation (Table 6). Plots of profiles from these average values (Fig. 15) compare favorably with representative profiles that were selected statistically from actual profiles in the MOODS database.

Table 6 — Monthly Temperature, Salinity, and Sound Speed Averages from September and October for Six Regions (Section 3.3)

Eastern Shore (Subarea 13)

	Sept			Oct		
Depth	**T (C)**	**S (PSU)**	**SS (m/s)**	**T (C)**	**S (PSU)**	**SS (m/s)**
0	16.36	30.54	1506.235	13.25	30.39	1495.985
10	15.61	30.72	1504.268	12.66	30.19	1493.891
20	14.22	30.74	1499.975	12.26	30.55	1493.121
30	11.43	31.17	1491.145	11.05	31.1	1489.709
50	4.96	32.1	1467.8	6.23	31.93	1472.773
75	3.59	32.61	1463.129	4.02	32.31	1464.56
100	4.79	33.15	1469.317	4.51	32.92	1467.853
150	7.46	33.74	1481.654	7.33	33.64	1481.028
200						
250						

South Shore (Subarea 14)

	Sept			Oct		
Depth	**T (C)**	**S (PSU)**	**SS (m/s)**	**T (C)**	**S (PSU)**	**SS (m/s)**
0	16.1	30.72	1505.643	13.08	30.76	1495.867
10	14.79	30.77	1501.707	12.2	30.89	1493.172
20	12.35	31.36	1494.438	11.68	31.06	1491.731
30	9.11	31.64	1483.274	10.55	31.32	1488.187
50	4.25	32.16	1464.913	6.13	31.97	1472.423
75	3.23	32.54	1461.491	3.99	32.44	1464.608
100	4.04	33.03	1466.016	4.33	33.07	1467.3
150	7.38	34.12	1481.842	7.33	33.64	1481.034
200						
250						

Emerald Basin (Subarea 12)

	Sept			Oct		
Depth	**T (C)**	**S (PSU)**	**SS (m/s)**	**T (C)**	**S (PSU)**	**SS (m/s)**
0	16.83	31.25	1508.53	13.65	31.17	1498.29
10	16.51	31.22	1507.68	13.49	31.32	1498.11
20	14.21	31.58	1500.97	13.33	31.46	1497.91
30	10.08	32.05	1487.40	11.35	31.85	1491.72
50	4.31	32.57	1465.72	5.69	32.75	1471.67
75	4.53	33.27	1467.99	4.91	33.36	1469.69
100	6.46	33.8	1476.98	6.31	33.88	1476.49
150	8.17	34.51	1485.40	8.42	34.57	1486.44
200	8.72	34.71	1488.56	8.83	34.78	1489.09
250	8.51	34.71	1488.59	8.9	34.85	1490.27

Table 6 — Monthly Temperature, Salinity, and Sound Speed Averages from September and October for Six Regions (Section 3.3), cont'd

LaHave Basin (Subarea 15)						
	Sept			Oct		
Depth	T (C)	S (PSU)	SS (m/s)	T (C)	S (PSU)	SS (m/s)
0	15.89	30.97	1505.29	13.34	30.93	1496.96
10	15.03	30.93	1502.68	13.23	31.03	1496.87
20	12.14	31.82	1494.29	12.63	31.21	1495.22
30	8.12	32.13	1480.14	10.67	31.42	1488.75
50	4.06	32.45	1464.50	5.66	32.38	1471.06
75	4.27	33.11	1466.68	4.7	32.89	1468.19
100	5.51	33.47	1472.71	6.02	33.53	1474.87
150	7.97	34.26	1484.31	8.36	34.57	1486.22
200	8.35	34.69	1487.14	8.86	34.83	1489.27
250	8.42			8.55		

Western Bank (Subarea 10)						
	Sept			Oct		
Depth	T (C)	S (PSU)	SS (m/s)	T (C)	S (PSU)	SS (m/s)
0	17.27	31.51	1510.17	13.9	31.72	1499.80
10	16.97	31.6	1509.54	14.27	31.73	1501.19
20	14.52	31.87	1502.34	13.57	31.83	1499.17
30	11.58	32.07	1492.81	11.87	31.95	1493.68
50	6.33	32.54	1473.97	7.44	32.87	1478.81
75	5.52	33.32	1472.14	5.32	33.22	1471.20
100	6.18	33.32	1475.22	5.72	33.67	1473.84
150	9.25	33.49	1488.14	7.42	34.59	1482.63
200	8.94	34.2	1488.72	9.83		
250	9.45					

Emerald Bank (Subarea 11)						
	Sept			Oct		
Depth	T (C)	S (PSU)	SS (m/s)	T (C)	S (PSU)	SS (m/s)
0	17.35	31.54	1510.45	14.26	31.62	1500.86
10	17.05	31.47	1509.62	14.19	31.57	1500.73
20	15.22	31.72	1504.41	13.79	31.7	1499.74
30	10.91	32.31	1490.73	12.35	32.07	1495.49
50	5.43	32.82	1470.70	7.41	32.92	1478.75
75	6.15	33.37	1474.76	6.36	33.53	1475.82
100	6.91	33.44	1478.29	6.96	33.9	1479.10
150				8.21		
200				9.55		
250				7.87	34.96	1486.51

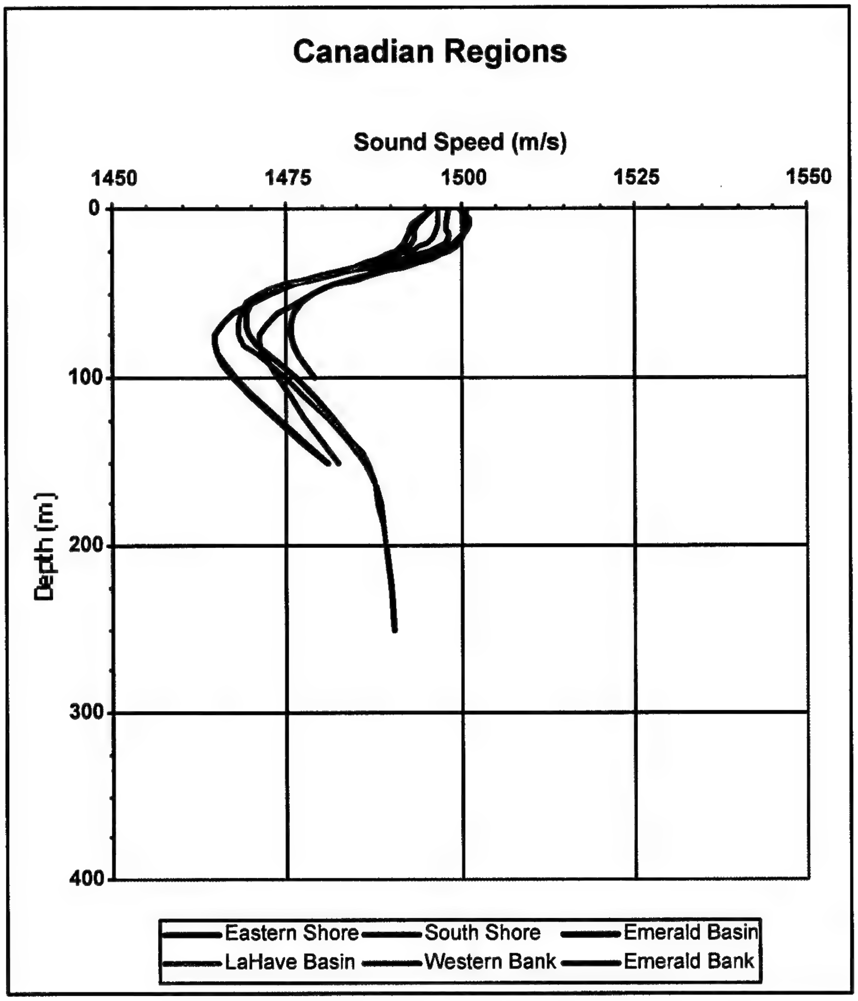

Fig. 15 — Sound speed profiles of Scotian Shelf regions identified in Section 3.3 for September and October, calculated from monthly averages (Table 6) for the six regions identified in Section 3.3

4. GEOLOGY AND GEOACOUSTICS

Geoacoustic properties of the Scotian Shelf are well known after several decades of measurements and research. However, the sediment distribution in the area is complex. The continental shelf of Nova Scotia was significantly modified by glaciation and is characterized by a series of glacial moraines that run nearly parallel to the coast (see Fig. 2). Reworking of these glacial deposits by currents and storms and more recent (quaternary) sediment deposits from river runoff and currents have resulted in three or four acoustically distinct layers in most areas. However, in some areas, undisturbed glacial tills are occasionally exposed on the basin slopes.

This section describes the geology of the Scotian Shelf as determined from the literature and previous measurements. It also provides a set of geoacoustic models based on the general geologic framework and average grain size properties, after some assumptions are made about the compaction of the sediments. These models reflect a sub-bottom structure that has three distinct acoustic layers.

4.1 Bedrock of the Scotian Shelf

Three types of bedrock are found in the area of the proposed experimental sites. The first extends out from the shore to approximately 160 m water depth. Here, the Scotian Shelf is underlain by rocks of the Meguma group - a section of undifferentiated Cambrian to Devonian material (King and MacLean 1976). Seaward of this formation is the central section of Emerald Basin, which is underlain by Cretaceous material. Further offshore, the outer banks are underlain by tertiary formations, which seem to be associated with hydrocarbon deposits. Acoustically, the bedrock forming the acoustic basement is simplified to two different forms: the metamorphic Meguma group and the younger, largely nonmetamorphic cretaceous and tertiary section.

4.2 Sediments of the Scotian Shelf

Five major quaternary deposits overlay the bedrock of the Scotian shelf. These are LaHave Clay, Sable Island Sand and Gravel, Sambro Sand, Emerald Silt, and Scotian Shelf Drift (Keen and Williams 1990). Considered together, the geographic distribution of these deposits (Figs. 16(a) and (b)) and vertical section across the inner shelf, Emerald Basin, and Emerald Bank (Fig. 17) give a three-dimensional view of the bottom structure on the Scotian Shelf. A description of each sediment type follows (King 1967):

1. <u>LaHave clay.</u> These silty-clay facies tend to conform to the shape of the basins, with some irregular outcrop patterns north of the moraine ridges. They form the upper sediment layer of most basins on the shelf. These facies have a mean diameter of 0.003 mm (8.4 phi units) and are well sorted. In the southern portion of Emerald Basin and the northern portion of LaHave Basin, the clay tends toward clayey silt (7.4 phi units). The thickness of the unit lies between 10 and 20 m.
2. <u>Sable Island sand and gravel</u>. This formation consists of sand, gravel, and sand and gravel mixtures dropped by glaciers. The mixture is defined as two groups: a dominantly gravel group having more than 50 percent gravel and a dominantly sand group having more than 50 percent sand. This formation appears to have arisen from mainland Nova Scotia and represents outwash from glaciers that covered the island. Grain size is probably quite variable, along with other physical properties.
3. <u>Sambro sand.</u> The Sambro sand represents a littoral zone deposition and, in general, is restricted to a thin belt along the paleo-shoreline, and a larger belt along the seaward edge of the banks. This sand has silt and clay content on the order of 10 and 5 percent, respectively; thus it can be considered partially to poorly sorted. The mean grain size appears to be on the order 0.2 mm (2.3 phi units). The layer thickness ranges from a thin veneer to 80 m.
4. <u>Emerald silt.</u> The main silt facies are confined to bands along the periphery of the basins. In general, this silt is poorly sorted, indicating short-range transport and has a mean grain size of 0.01 to 0.05 mm (4.3 to 6.4 phi units). The silt layer is distributed extensively, found as a subcrop in all basins. Thicknesses of at least 40 m are recorded.

5. Scotian Shelf drift. Scotian Drift is a glacial till, with a mean grain in the sand range, but the consistency of an undifferentiated mixture ranging from rock flour to boulders. This till is seen both as a surface outcrop between the 130- to 140-m depth contours and between the 200- to 210-m depth contours and with other outcrops on banks and saddles. The surface expression is largely controlled by the deposition of clay materials over its surface in low current areas. The drift has a vertical extent of up to 100 m, shows stratification in some areas, and is typical of normal ground moraine.

Near Halifax, the sediment is chiefly Sable Island sand and gravel. Sidescan surveys for the outer Halifax Harbor and the area north of Chebucto Head depict details of the sediment distribution. They show an area of mainly sand or muddy sand (usually in thin deposits) within 2 km of the coast. Gravel and bedrock outcroppings generally occur outside of 2 km, but are occasionally very close (within 0.5 km) to the coast (Fader et al. 1991). Similar seabed properties are expected at the Halifax Harbor trial site, slightly south of Chebucto Head.

The Emerald Basin location is generally characterized by a 5- to 10-m surficial layer of LaHave clay, overlying a 15- to 25-m layer of Emerald silt, on top of Scotian Shelf drift. The total Quaternary sediment thickness is approximately 30 m (Fig. 17). The seabed surface shows few trawl marks, and abundant pockmarks, indicating a possibility of trapped gas within the top sediment layers (Moran et al. 1991). Figure 18 presents samples of sidescan records for this area (Gilbert et al. 1996).

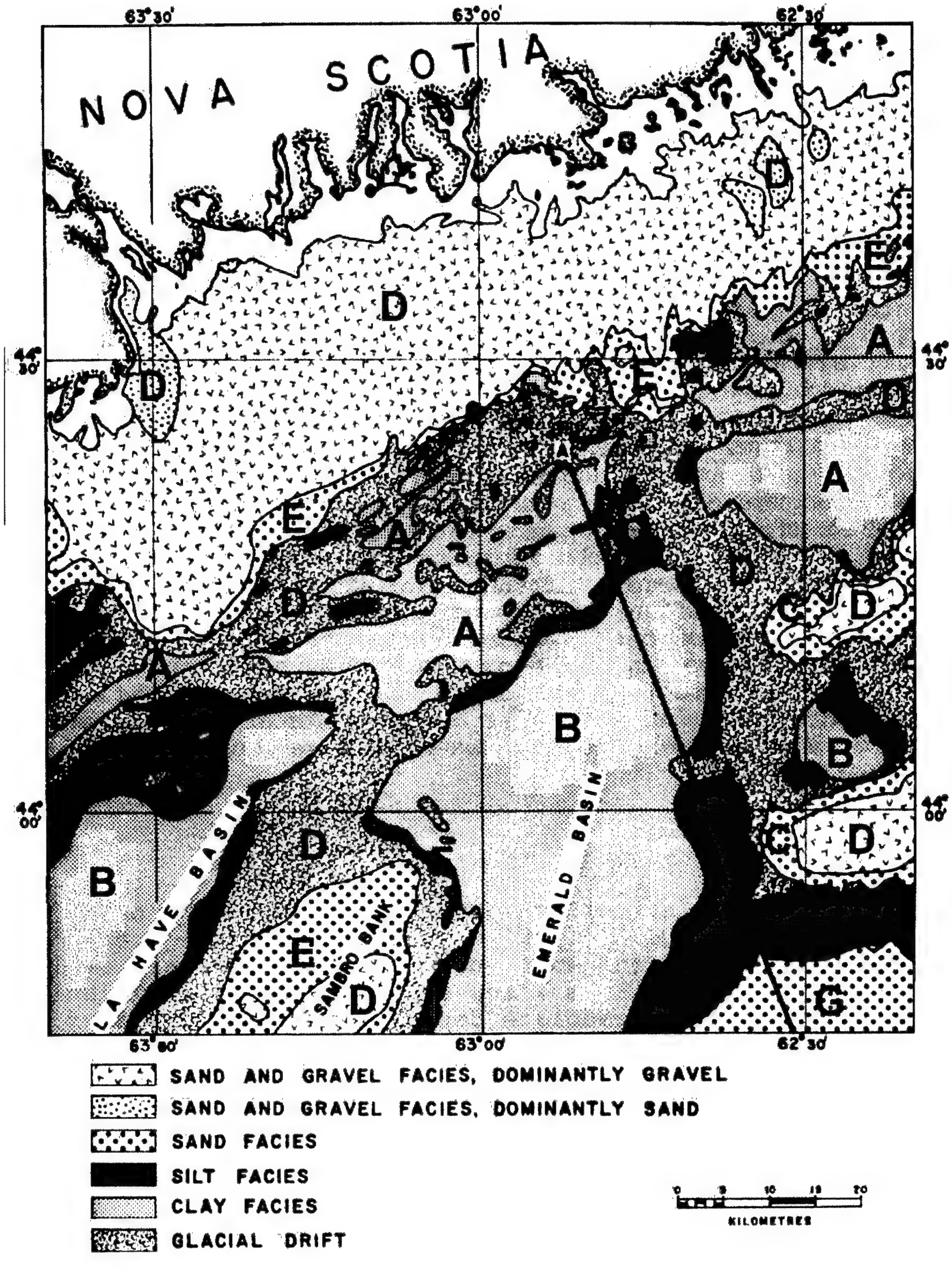

Fig. 16(a) — Surface sediment distribution on the Scotian shelf. Letters correspond to geoacoustic models provided in Tables 10 through 19 (after King 1967).

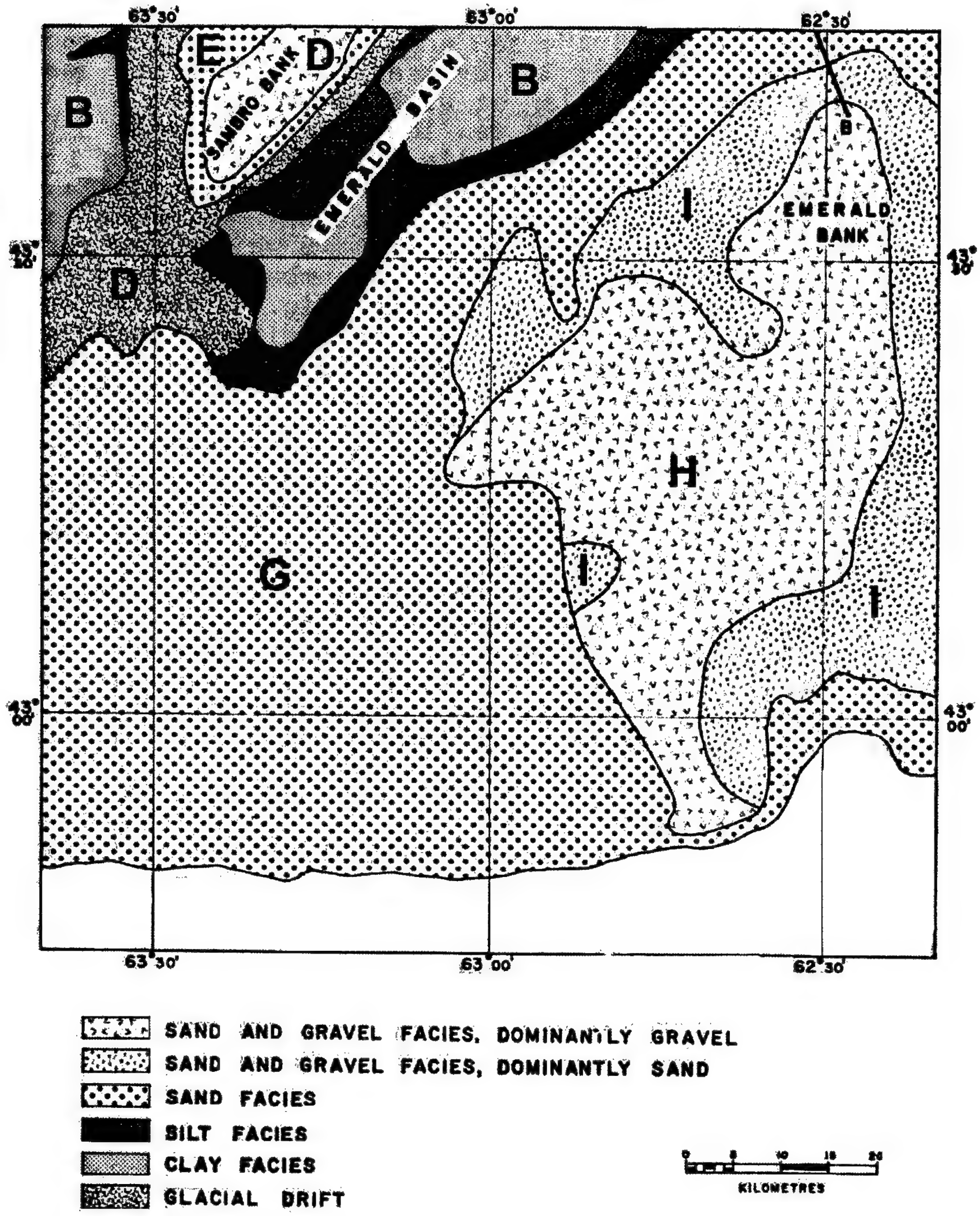

Fig. 16(b) — Surface sediment distribution on the Scotian Shelf. Letters correspond to geoacoustic models provided in Tables 10 through 19 (after King 1967).

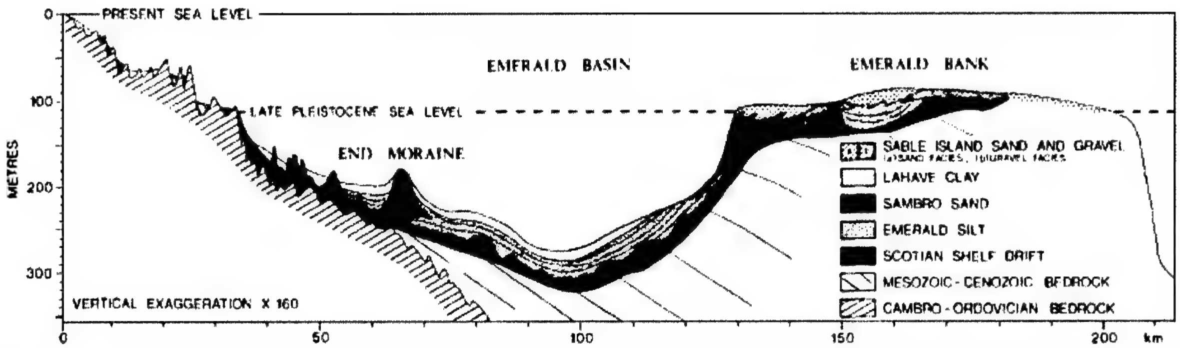

Fig. 17 — Cross section of Scotian Shelf sediments across the inner shelf, Emerald Basin, and Emerald Bank (after http://museum.gov.ns.ca/mnh/nature/nhns/index.htm, T3.5)

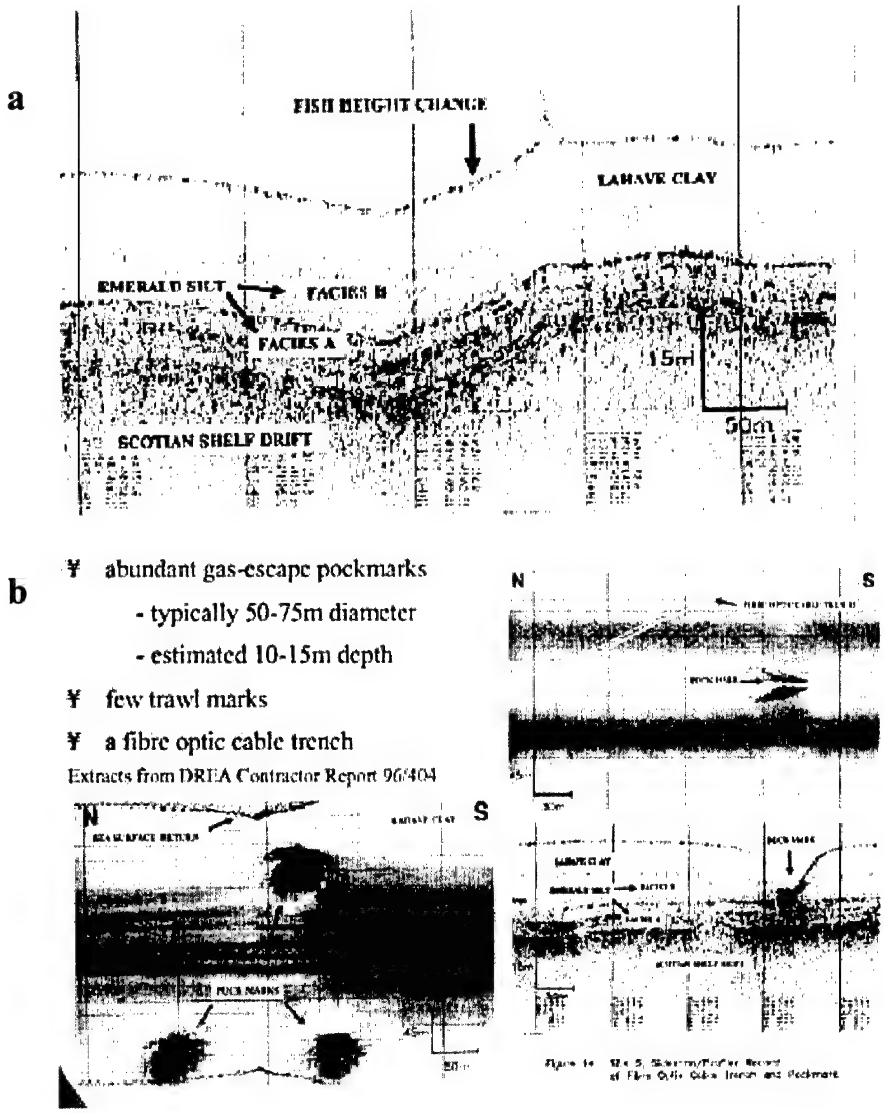

Fig. 18 — Sidescan sonar data for the Emerald Basin showing (a) sediment layering and (b) seabed features

4.3 Geoacoustic Parameters

Published values of geoacoustic parameters for sediments from the two proposed test areas have been assembled. Tables 7 and 8 summarize ranges of these parameters with references for the areas near Halifax and the Emerald Basin, respectively (Osler 1994).

Table 7 — Geoacoustic Parameters for Sediments in the Halifax Area as Suggested by the Literature

Sand	Value	Reference
Compressional Velocity (v_p)	1.550 – 1.640 km/s	Dodds (1990)
	1.572 – 1.661 km/s	McKay and McKay (1982)
	1.595 – 1.775 km/s	Hunter et al. (1982)
Shear Velocity (v_s)	0.260 km/s	Brocher (1983)
Attenuation (k)	0.037 dB/m-kHz	Beebe and McDaniel (1980)
	0.22 dB/m-kHz	Dodds (1980)
Density (ρ)	1.96 g/cm^3	Beebe and McDaniel (1980)
	1.7 g/cm^3	Brocher (1983)
Gravel		
Compressional Velocity (v_p)	1.850 – 1.900 km/s	Beebe and McDaniel (1980)
	1.670 – 1.780 km/s	Dodds (1990)
Attenuation (k)	0.009 dB/m-kHz	Beebe and McDaniel (1980)
Density (ρ)	2.06 g/cm^3	Beebe and McDaniel (1980)

Table 8 — Geoacoustic Parameters for the Emerald Basin as Suggested by the Literature

LaHave Clay	Value	Reference
Compressional Velocity (v_p)	1.460 – 1.490 km/s	Dodds (1990)
	1.261 – 1.420 km/s	McKay and McKay (1982)
	1.480 – 1.490 km/s	Beebe and McDaniel (1980)
Attenuation (k)	0.056 dB/m-kHz	Beebe and McDaniel (1980)
	0.23 dB/m-kHz	Dodds (1980)
Density (ρ)	1.50 – 1.54 g/cm^3	Beebe and McDaniel (1980)
Emerald Silt		
Compressional Velocity (v_p)	1.480 – 1.590 km/s	Hunter et al. (1982)
	1.550 – 1.600 km/s	Beebe and McDaniel (1980)
	1.470 – 1.530 km/s	Dodds (1990)
	1.430 – 1.520 km/s	Dodds (1990)
Attenuation (k)	0.056 dB/m-kHz	Beebe and McDaniel (1980)
	0.22 dB/m-kHz	Dodds (1980)
Density (ρ)	1.56 g/cm^3	Beebe and McDaniel (1980)
Scotian Shelf Drift		
Compressional Velocity (v_p)	1.745 – 1.92 km/s	Hunter et al. (1982)
	1.550 – 1.600 km/s	Dodds (1990)
Attenuation (k)	0.0065 dB/m-kHz	Beebe and McDaniel (1980)
Density (ρ)	2.1 g/cm^3	Beebe and McDaniel (1980)

4.4 Geoacoustic Models

To predict the geoacoustic properties of an area, it is necessary to have knowledge of the three-dimensional structure of the seafloor. Information on the geological structure of the bedrock, which forms the acoustic basement, and the overlying sediments is required. In addition, there must be either direct measurements of the elastic and plastic properties of the sediments or an understanding of the diagenetic processes that have occurred in the sediments to affect these properties. Fortunately, the surficial and bedrock geology of the Scotian Shelf are reasonably well known. However, the early stage diagenesis of the quaternary sediments that compose the Scotian shelf is not well understood. The general process involves dewatering and compaction of the sediments, but there is controversy in the details.

Ten geoacoustic models were developed by the Naval Research Laboratory (NRL) for the Nova Scotian Shelf based on Hamilton's empirical approach (Hamilton 1980). His method addresses the problem of dewatering, solid state-stress realignment, or cementation process only in an empirical manner. Each model is constructed from the shelf geology described in Sections 4.1 and 4.2 and uses 'typical' values for geoacoustic parameters associated with grain size and vertical distribution of each sediment type. The present approach is simplified by assuming that:

1. clay and silt size fractions have linear vertical gradations in physical properties (this is assumed even though measurements of clays tend to show little vertical change in properties in the first few meters, and despite known problems with obtaining meaningful core samples in the upper layers of noncohesive sediments),
2. buried sand size material shows no vertical gradients (assumed due to inelastic compaction), and
3. tills have constant properties with depth (assumed for lack of a better model; however, tills are known to be heterogeneous, are designated as undifferentiated, and are difficult to estimate average properties).

Table 9 cross-references the sediment type and location (Figs. 16(a) and (b)) with the appropriate geoacoustic model. Tables 10 through 19 give the actual model values. These models represent several acoustically distinct layers formed from bedrock overlain by a glacial deposit, which in turn is overlain by quaternary sediments. Velocities of each layer are based on mean grain size (with the exception of the glacial till, which is assumed to have the same properties as the sandy gravel). Again, the velocities and densities are based on average properties for the material in question. Sediment sound speeds are based on an assumed bottom water sound speed of 1470 m/s. For implementation, each model corresponds to a surface sediment area depicted in Figs. 16(a) and (b) with labels 'A' through 'J.' The models for Areas 'C' through 'F' are the same as those of models 'G' through 'J,' respectively, except for the acoustic basement parameters (values in the final row of each model). The approximate division between the two basement types occurs just south of the Emerald Basin. Note that the Devonian aged granites (Osler 1994) south of the Chebucto Head area, are not included in these models. Also, some surface sediment types have been combined to simplify distributions. Specifically, glacial till (i.e., Scotian Drift) and the dominantly gravel facies are both represented by the geoacoustic model 'D.' And both sand and gravel facies (one dominantly sand and the other dominantly gravel) have been combined into one sand/gravel facies since the proportions are similar and the mapped regions overlap.

The possibility of hydrocarbon seeps has been largely ignored in this analysis. The location of wells suggest that source rock for the hydrocarbons are probably tertiary in age, which implies that seeps are more likely in the southern section of Emerald Basin and the band areas. There is a possibility that hydrocarbons migrate along fault and bedding planes, but detailed geological information to support or deny this hypothesis is lacking.

Table 9 — Cross-Referenced Sediment Type and Location with the Appropriate Geoacoustic Model

Location (Fig. 16)	Sediment Description	Basement	Geoacoustic Model
A	LaHave Clay / Scotian Drift	Metamorphic	Table 10
B	LaHave Clay/ Emerald Silt / Scotian Drift	Metamorphic	Table 11
C	Sambro Sand / Scotian Drift	Metamorphic	Table 12
D	Scotian Drift	Metamorphic	Table 13
E	Gravelly Sand / Scotian Drift	Metamorphic	Table 14
F	Emerald Silt / Scotian Drift	Metamorphic	Table 15
G	Sambro Sand / Scotian Drift	Sedimentary	Table 16
H	Scotian Drift (same as sandy gravel)	Sedimentary	Table 17
I	Sable Island Gravelly Sand / Scotian Drift	Sedimentary	Table 18
J	Emerald Silt / Scotian Drift	Sedimentary	Table 19

Table 10 — Area A; LaHave Clay Overlying Scotia Drift with a Metamorphic Basement

Depth (m)	Density (gm/cm^3)	Sound Speed (m/s)	Attenuation (dB/m kHz)	Shear Sound Speed (m/s)	Shear Attenuation (dB/m kHz)
0	1.40633	1449.608	0.03759	103.588	17.30000
2	1.40911	1451.032	0.03777	127.431	17.38323
4	1.41190	1452.456	0.03795	131.471	17.46562
6	1.41467	1453.880	0.03813	134.885	17.54717
8	1.41745	1455.304	0.03830	137.829	17.62789
10	1.42021	1456.728	0.03848	140.438	17.70779
12	2.17518	1845.356	0.10446	193.695	5.66527
14	2.17518	1851.543	0.10065	204.808	5.45844
16	2.17518	1856.614	0.09764	214.359	5.29507
18	2.17518	1860.912	0.09516	222.781	5.16077
20	2.17518	1864.643	0.09307	230.344	5.04718
22	2.17518	1867.940	0.09126	237.227	4.94907
24	2.17518	1870.895	0.08967	243.559	4.86292
26	2.17518	1873.571	0.08826	249.432	4.78628
28	2.17518	1876.018	0.08699	254.917	4.71737
30	2.17518	1878.272	0.08583	260.070	4.65486
32	2.17518	1880.361	0.08478	264.933	4.59772
34	2.17518	1882.308	0.08381	269.542	4.54515
36	2.17518	1884.131	0.08291	273.926	4.49653
38	2.17518	1885.845	0.08208	278.110	4.45132
40	2.17518	1887.463	0.08130	282.112	4.40912
42	2.60000	3500.000	0.02000	2100.000	0.05000

Table 11 — Area B; LaHave Clay Overlying Emerald Silt Overlying Scotia Drift with a Metamorphic Basement (Occurs Within the Banks)

Depth (m)	Density (gm/cm^3)	Sound Speed (m/s)	Attenuation (dB/m kHz)	Shear Sound Speed (m/s)	Shear Attenuation (dB/m kHz)
0	1.40633	1449.608	0.03759	103.588	17.30000
2	1.40911	1451.032	0.03777	127.431	17.38323
4	1.41190	1452.456	0.03795	131.471	17.46562
6	1.41467	1453.880	0.03813	134.885	17.54717
8	1.41745	1455.304	0.03830	137.829	17.62789
10	1.42021	1456.728	0.03848	140.438	17.70779
12	1.72644	1557.382	0.15634	188.114	14.38991
14	1.72859	1559.708	0.15586	194.550	14.34585
16	1.73075	1561.814	0.15551	200.176	14.31353
18	1.73290	1563.769	0.15524	205.206	14.28903
20	1.73505	1565.612	0.15504	209.775	14.27007
22	1.73719	1567.371	0.15488	213.977	14.25520
24	1.73933	1569.062	0.15475	217.876	14.24348
26	1.74147	1570.698	0.15465	221.524	14.23423
28	1.74360	1572.289	0.15457	224.956	14.22697
30	1.74573	1573.842	0.15451	228.202	14.22133
32	1.74785	1575.363	0.15446	231.287	14.21703
34	2.17518	1876.018	0.08699	254.917	4.71737
36	2.17518	1878.272	0.08583	260.070	4.65486
38	2.17518	1880.361	0.08478	264.933	4.59772
40	2.17518	1882.308	0.08381	269.542	4.54515
42	2.17518	1884.131	0.08291	273.926	4.49653
44	2.17518	1885.845	0.08208	278.110	4.45132
46	2.17518	1887.463	0.08130	282.112	4.40912
48	2.17518	1888.994	0.08057	285.951	4.36957
50	2.17518	1890.448	0.07989	289.642	4.33237
52	2.17518	1891.832	0.07924	293.196	4.29728
54	2.17518	1893.153	0.07863	296.626	4.26409
56	2.17518	1894.415	0.07805	299.941	4.23262
58	2.17518	1895.625	0.07750	303.149	4.20270
60	2.17518	1896.786	0.07697	306.259	4.17421
62	2.17518	1897.902	0.07647	309.277	4.14701
64	2.60000	3500.000	0.02000	2100.000	0.05000

Table 12 — Area C; Sambro Sand Overlying Scotian Drift with a Metamorphic Basement

Depth (m)	Density (gm/cm^3)	Sound Speed (m/s)	Attenuation (dB/m kHz)	Shear Sound Speed (m/s)	Shear Attenuation (dB/m kHz)
0	2.00000	1629.755	0.29164	51.903	13.20000
2	2.00000	1722.476	0.15770	130.529	7.13779
4	2.00000	1740.478	0.14050	155.226	6.35905
6	2.17518	1837.410	0.10959	180.254	5.94352
8	2.17518	1845.356	0.10446	193.695	5.66527
10	2.17518	1851.543	0.10065	204.808	5.45844
12	2.17518	1856.614	0.09764	214.359	5.29507
14	2.17518	1860.912	0.09516	222.781	5.16077
16	2.17518	1864.643	0.09307	230.344	5.04718
18	2.17518	1867.940	0.09126	237.227	4.94907
20	2.17518	1870.895	0.08967	243.559	4.86292
22	2.17518	1873.571	0.08826	249.432	4.78628
24	2.17518	1876.018	0.08699	254.917	4.71737
26	2.17518	1878.272	0.08583	260.070	4.65486
28	2.17518	1880.361	0.08478	264.933	4.59772
30	2.17518	1882.308	0.08381	269.542	4.54515
32	2.17518	1884.131	0.08291	273.926	4.49653
34	2.17518	1885.845	0.08208	278.110	4.45132
36	2.17518	1887.463	0.08130	282.112	4.40912
38	2.60000	3500.000	0.02000	2100.000	0.05000

Table 13 — Area D; Scotia Drift or Sandy Gravel with a Metamorphic Basement*

Depth (m)	Density (gm/cm^3)	Sound Speed (m/s)	Attenuation (dB/m kHz)	Shear Sound Speed (m/s)	Shear Attenuation (dB/m kHz)
0	2.17518	1710.088	0.24340	54.461	13.20000
2	2.17518	1807.379	0.13162	136.963	7.13779
4	2.17518	1826.269	0.11726	162.878	6.35905
6	2.17518	1837.410	0.10959	180.254	5.94352
8	2.17518	1845.356	0.10446	193.695	5.66527
10	2.17518	1851.543	0.10065	204.808	5.45844
12	2.17518	1856.614	0.09764	214.359	5.29507
14	2.17518	1860.912	0.09516	222.781	5.16077
16	2.17518	1864.643	0.09307	230.344	5.04718
18	2.17518	1867.940	0.09126	237.227	4.94907
20	2.17518	1870.895	0.08967	243.559	4.86292
22.	2.17518	1873.571	0.08826	249.432	4.78628
24	2.17518	1876.018	0.08699	254.917	4.71737
26	2.17518	1878.272	0.08583	260.070	4.65486
28	2.17518	1880.361	0.08478	264.933	4.59772
30	2.17518	1882.308	0.08381	269.542	4.54515
32	2.60000	3500.000	0.02000	2100.000	0.05000

* **Note**: Drift and till are acoustically very similar to sandy gravel and are not differentiated here.

Table 14 — Area E; Gravelly Sand Overlying Scotian Drift with a Metamorphic Basement

Depth (m)	**Density (gm/cm^3)**	**Sound Speed (m/s)**	**Attenuation (dB/m kHz)**	**Shear Sound Speed (m/s)**	**Shear Attenuation (dB/m kHz)**
0	2.10706	1677.376	0.26216	53.420	13.20000
2	2.10706	1772.806	0.14176	134.343	7.13779
4	2.10706	1791.334	0.12629	159.762	6.35905
6	2.10706	1802.262	0.11804	176.806	5.94352
8	2.10706	1810.056	0.11252	189.990	5.66527
10	2.10706	1816.125	0.10841	200.890	5.45844
12	2.17518	1856.614	0.09764	214.359	5.29507
14	2.17518	1860.912	0.09516	222.781	5.16077
16	2.17518	1864.643	0.09307	230.344	5.04718
18	2.17518	1867.940	0.09126	237.227	4.94907
20	2.17518	1870.895	0.08967	243.559	4.86292
22	2.17518	1873.571	0.08826	249.432	4.78628
24	2.17518	1876.018	0.08699	254.917	4.71737
26	2.17518	1878.272	0.08583	260.070	4.65486
28	2.17518	1880.361	0.08478	264.933	4.59772
30	2.17518	1882.308	0.08381	269.542	4.54515
32	2.17518	1884.131	0.08291	273.926	4.49653
34	2.17518	1885.845	0.08208	278.110	4.45132
36	2.17518	1887.463	0.08130	282.112	4.40912
38	2.17518	1888.994	0.08057	285.951	4.36957
40	2.17518	1890.448	0.07989	289.642	4.33237
42	2.60000	3500.000	0.02000	2100.000	0.05000

Table 15 — Area F; Emerald Silt over Scotian Drift with a Metamorphic Basement

Depth (m)	Density (gm/cm^3)	Sound Speed (m/s)	Attenuation (dB/m kHz)	Shear Sound Speed (m/s)	Shear Attenuation (dB/m kHz)
0	1.71776	1526.377	0.17816	95.772	16.39800
2	1.71994	1546.593	0.16030	157.642	14.75418
4	1.72211	1551.413	0.15812	170.981	14.55420
6	1.72427	1554.711	0.15703	180.501	14.45336
8	1.72644	1557.382	0.15634	188.114	14.38991
10	1.72859	1559.708	0.15586	194.550	14.34585
12	1.73075	1561.814	0.15551	200.176	14.31353
14	1.73290	1563.769	0.15524	205.206	14.28903
16	1.73505	1565.612	0.15504	209.775	14.27007
18	1.73719	1567.371	0.15488	213.977	14.25520
20	1.73933	1569.062	0.15475	217.876	14.24348
22	2.17518	1876.018	0.08699	254.917	4.71737
24	2.17518	1878.272	0.08583	260.070	4.65486
26	2.17518	1880.361	0.08478	264.933	4.59772
28	2.17518	1882.308	0.08381	269.542	4.54515
30	2.17518	1884.131	0.08291	273.926	4.49653
32	2.17518	1885.845	0.08208	278.110	4.45132
34	2.17518	1887.463	0.08130	282.112	4.40912
36	2.17518	1888.994	0.08057	285.951	4.36957
38	2.17518	1890.448	0.07989	289.642	4.33237
40	2.17518	1891.832	0.07924	293.196	4.29728
42	2.17518	1893.153	0.07863	296.626	4.26409
44	2.17518	1894.415	0.07805	299.941	4.23262
46	2.17518	1895.625	0.07750	303.149	4.20270
48	2.17518	1896.786	0.07697	306.259	4.17421
50	2.17518	1897.902	0.07647	309.277	4.14701
52	2.60000	3500.000	0.02000	2100.000	0.05000

Table 16 — Area G; Sambro Sand Overlying Scotia Drift with a Sedimentary Basement

Depth (m)	Density (gm/cm^3)	Sound Speed (m/s)	Attenuation (dB/m kHz)	Shear Sound Speed (m/s)	Shear Attenuation (dB/m kHz)
0	2.00000	1629.755	0.29164	51.903	13.20000
2	2.00000	1722.476	0.15770	130.529	7.13779
4	2.00000	1740.478	0.14050	155.226	6.35905
6	2.17518	1837.410	0.10959	180.254	5.94352
8	2.17518	1845.356	0.10446	193.695	5.66527
10	2.17518	1851.543	0.10065	204.808	5.45844
12	2.17518	1856.614	0.09764	214.359	5.29507
14	2.17518	1860.912	0.09516	222.781	5.16077
16	2.17518	1864.643	0.09307	230.344	5.04718
18	2.17518	1867.940	0.09126	237.227	4.94907
20	2.17518	1870.895	0.08967	243.559	4.86292
22	2.17518	1873.571	0.08826	249.432	4.78628
24	2.17518	1876.018	0.08699	254.917	4.71737
26	2.17518	1878.272	0.08583	260.070	4.65486
28	2.17518	1880.361	0.08478	264.933	4.59772
30	2.17518	1882.308	0.08381	269.542	4.54515
32	2.17518	1884.131	0.08291	273.926	4.49653
34	2.17518	1885.845	0.08208	278.110	4.45132
36	2.17518	1887.463	0.08130	282.112	4.40912
38	2.30000	2500.000	0.04000	1100.000	0.08000

Table 17 — Area H; Scotia Drift or Sandy Gravel with a Sedimentary Basement

Depth (m)	Density (gm/cm^3)	Sound Speed (m/s)	Attenuation (dB/m kHz)	Shear Sound Speed (m/s)	Shear Attenuation (dB/m kHz)
0	2.17518	1710.088	0.24340	54.461	13.20000
2	2.17518	1807.379	0.13162	136.96	7.13779
4	2.17518	1826.269	0.11726	162.87	6.35905
6	2.17518	1837.410	0.10959	180.25	5.94352
8	2.17518	1845.356	0.10446	193.69	5.66527
10	2.17518	1851.543	0.10065	204.80	5.45844
12	2.17518	1856.614	0.09764	214.35	5.29507
14	2.17518	1860.912	0.09516	222.78	5.16077
16	2.17518	1864.643	0.09307	230.34	5.04718
18	2.17518	1867.940	0.09126	237.22	4.94907
20	2.17518	1870.895	0.08967	243.55	4.86292
22	2.17518	1873.571	0.08826	249.43	4.78628
24	2.17518	1876.018	0.08699	254.91	4.71737
26	2.17518	1878.272	0.08583	260.07	4.65486
28	2.17518	1880.361	0.08478	264.93	4.59772
30	2.17518	1882.308	0.08381	269.54	4.54515
32	2.30000	2500.000	0.04000	1100.000	0.08000

Table 18 — Area I; Sable Island Gravelly Sand Overlying Scotian Drift with a Sedimentary Basement

Depth (m)	Density (gm/cm^3)	Sound Speed (m/s)	Attenuation (dB/m kHz)	Shear Sound Speed (m/s)	Shear Attenuation (dB/m kHz)
0	2.10706	1677.376	0.26216	53.420	13.20000
2	2.10706	1772.806	0.14176	134.343	7.13779
4	2.10706	1791.334	0.12629	159.762	6.35905
6	2.10706	1802.262	0.11804	176.806	5.94352
8	2.10706	1810.056	0.11252	189.990	5.66527
10	2.10706	1816.125	0.10841	200.890	5.45844
12	2.17518	1856.614	0.09764	214.359	5.29507
14	2.17518	1860.912	0.09516	222.781	5.16077
16	2.17518	1864.643	0.09307	230.344	5.04718
18	2.17518	1867.940	0.09126	237.227	4.94907
20	2.17518	1870.895	0.08967	243.559	4.86292
22	2.17518	1873.571	0.08826	249.432	4.78628
24	2.17518	1876.018	0.08699	254.917	4.71737
26	2.17518	1878.272	0.08583	260.070	4.65486
28	2.17518	1880.361	0.08478	264.933	4.59772
30	2.17518	1882.308	0.08381	269.542	4.54515
32	2.17518	1884.131	0.08291	273.926	4.49653
34	2.17518	1885.845	0.08208	278.110	4.45132
36	2.17518	1887.463	0.08130	282.112	4.40912
38	2.17518	1888.994	0.08057	285.951	4.36957
40	2.17518	1890.448	0.07989	289.642	4.33237
42	2.30000	2500.000	0.04000	1100.000	0.08000

Table 19 — Area J; Emerald Silt over Scotian Drift with a Sedimentary Basement

Depth (m)	Density (gm/cm^3)	Sound Speed (m/s)	Attenuation (dB/m kHz)	Shear Sound Speed (m/s)	Shear Attenuation (dB/m kHz)
0	1.71776	1526.377	0.17816	95.772	16.39800
2	1.71994	1546.593	0.16030	157.642	14.75418
4	1.72211	1551.413	0.15812	170.981	14.55420
6	1.72427	1554.711	0.15703	180.501	14.45336
8	1.72644	1557.382	0.15634	188.114	14.38991
10	1.72859	1559.708	0.15586	194.550	14.34585
12	1.73075	1561.814	0.15551	200.176	14.31353
14	1.73290	1563.769	0.15524	205.206	14.28903
16	1.73505	1565.612	0.15504	209.775	14.27007
18	1.73719	1567.371	0.15488	213.977	14.25520
20	1.73933	1569.062	0.15475	217.876	14.24348
22	2.17518	1876.018	0.08699	254.917	4.71737
24	2.17518	1878.272	0.08583	260.070	4.65486
26	2.17518	1880.361	0.08478	264.933	4.59772
28	2.17518	1882.308	0.08381	269.542	4.54515
30	2.17518	1884.131	0.08291	273.926	4.49653
32	2.17518	1885.845	0.08208	278.110	4.45132
34	2.17518	1887.463	0.08130	282.112	4.40912
36	2.17518	1888.994	0.08057	285.951	4.36957
38	2.17518	1890.448	0.07989	289.642	4.33237
40	2.17518	1891.832	0.07924	293.196	4.29728
42	2.17518	1893.153	0.07863	296.626	4.26409
44	2.17518	1894.415	0.07805	299.941	4.23262
46	2.17518	1895.625	0.07750	303.149	4.20270
48	2.17518	1896.786	0.07697	306.259	4.17421
50	2.17518	1897.902	0.07647	309.277	4.14701
52	2.30000	2500.000	0.04000	1100.000	0.08000

5. METEOROLOGY

The area around Nova Scotia is under the influence of two major pressure systems: the Icelandic Low and Azores-Bermuda High. During the winter months of December, January, and February, the weakened Azores-Bermuda High is at its most eastern position in the Atlantic while the strengthened Icelandic Low extends far south and dominates the North Atlantic. As a result, there is a mean southwest flow over the eastern North Atlantic and a mean northwest flow over the western North Atlantic. By contrast, during the summer months of June, July, and August, the Icelandic Low is greatly reduced and influences only the area north of about 55 deg N. The remainder of the western North Atlantic is dominated by the expanded Azores-Bermuda High, which results in a mean south-southwest to southwest flow. Spring and autumn months are transitional. During autumn months of September, October, and November, the Azores-Bermuda High weakens while the Icelandic Low strengthens, and winds in the western North Atlantic gradually shift back to primarily westerly and northwesterly in direction (Williams and Godshall 1977).

On the Nova Scotian Shelf, the measured wind fields during September and October are the result of fluctuations due to the passage of major weather systems interacting with the semipermanent pressure zones discussed in Section 4. Statistics of historical wind and wave data are available for the area around Nova Scotia from the Canadian Department of Fisheries and Oceans web-site; http://www.meds-

sdmm.dfo-mpo.gc.ca/meds/Databases/WAVE/WAVE_e.htm (Fig. 19). Information summarized from the areas labeled Nova Scotian Shore (N. S. Shore), Sable, East Scotian Slope, and West Scotian Slope for September and October are descriptive of conditions expected at the RDS-4 test site (Tables 20 and 21). Graphs for each area are shown in Figs. 20 through 25. The N. S. Shore of these figures corresponds to the 'Eastern Shore' of Nova Scotia in Fig. 19.

In September, the winds are most often from the west and southwest directions at mostly 15 knots for all shore and slope areas near the proposed experiment site. In October, winds shift to more westerly direction and increase speed to mostly between 17 and 19 knots (Table 20 and Fig. 20). Gale-force winds (over 36 knots) have a low rate of occurrence in September and October (typically less than 5% of the time). In fact, 95% of winds are between 5 and 30 knots in September and between 5 and 35 knots in October (Table 20).

The distribution of historical wind speeds is similar at all four areas off Nova Scotia for the months of September and October, respectively (Fig. 21). Almost 70% of September winds were less than 20 knots (mostly 10-20 knots.); approximately 20% were 20 to 30 knots and less than 10% were over 30 knots. During October, the distribution shifted slightly to decrease the percentage of wind less than 10 knots and increase the percentage winds over 30 knots. Still, almost 60% of the winds were less than 20 knots; approximately 30% were between 20 and 30 knots and 10 to 15% were over 30 knots.

Waves at all shore and slope areas are statistically from the west and southwest in September, with 95% of significant wave heights ranging from 0.4 to 3.4 m, depending on location; most often 0.9 to 1.5 m. In October, waves are predominantly from the west with slightly larger wave heights; 95T of significant wave heights range from 0.4 to 4.5 m, most often 1.0 to 1.8 m (Table 21 and Fig. 22). In general, the sea direction appears to correspond with the wind direction (Figs. 21 and 22).

Some geographical variability can be seen in the distribution of historical wave height, with the smaller wave heights tending to the Nova Scotian Shore and highest wave heights in the Sable area. During September, over 70% of historical significant wave heights are less than 2 m; 2 to 3 m occur approximately 6 to 19% of the time and over 3 m occur less than 10% of the time. During October, the distribution shifts. The percentage of wave heights less than 2 m decreases and the percentage of wave heights greater than 2 m increases; less than 2 m occur as little as 41% of the time, 2 to 3 m occur 12% to 29% of the time, and greater than 3 m occur about 15% of the time (Fig. 23).

Wave peak period in September has generally been between 0 and 10 s, most often around 8 s. In October, the 8-s peak wave period appears even more dominant, with a decrease in many of the smaller periods (Fig. 24). Typically, seas (waves generated by local winds) have periods of less than 10 s while swell (waves generated by distant winds) have periods greater than 10 s, with some obvious overlap. Considering that the wind direction corresponds to the wave direction, and that the measured wave period is predominately less than 10 s, it appears that waves in the test area are produced predominately by local winds.

In summary, fairly strong wind and sea conditions are expected during the RDS-4 experiment based on historical data. At this time of year, winds are from the west and southwest often near 20 knots and waves are from the west and southwest usually at 1 to 2 m significant wave height with a peak period of 6 to 8 s. It is also important to note that winds well in excess 36 knots (gale force) and significant wave heights over 5 m have occurred in September and October.

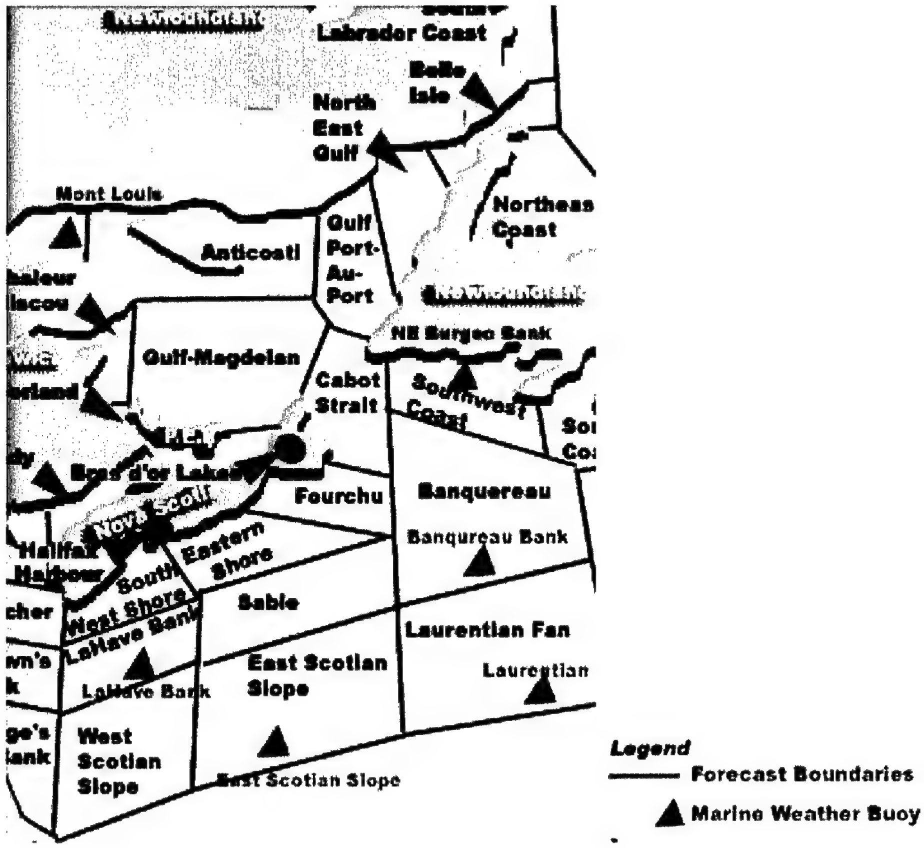

Fig. 19 — Locations of weather forecast areas off Nova Scotia (from http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Databases/WAVE/WAVE_e.htm)

Table 20 — Synopsis of Historical Wind Data in the Vicinity of RDS-4 Experimental Area during September and October by Forecast Area (from: http://www.medssdmm.dfompo.gc.ca/meds/Databases/WAVE/WAVE_e.htm)

Location	Month	Wind Dir. Prevail	Wind Speed (kt)				
			Avg	Med	Min	Max	95%
N.S. Shore	Sept	SW	16.3	15.0	0	51.3	5 - 30
	Oct	W	19.1	18.0	0	53.0	5 – 35
Sable	Sept	W	16.1	15.3	0	57.5	4.2 – 30.7
	Oct	W	18.8	18.0	0	76.0	5 – 35
E. Scotian Slope	Sep	W	15.2	15.0	0	67.4	5 – 30
	Oct	W	17.7	17.0	0	62.0	5 – 35
W. Scotian Slope	Sep	W	15.4	15.0	0	65.0	4 – 30
	Oct	W	17.9	17.0	0	87.4	5 - 35

Table 21 — Synopsis of Historical Wave Data in the Vicinity of RDS-4 Experimental Area during September and October by Forecast Area (from http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Databases/WAVE/WAVE_e.htm)

Location	Month	Direction (Prevail)	Significant Wave Height (m)				
			Avg	Med	Min	Max	95%
N.S. Shore	Sept	-	1.0	0.9	0.1	4.5	0.4 – 2.1
	Oct	-	1.3	1.0	0.1	5.9	0.4 – 2.8
Sable	Sept	-	1.6	1.4	0.4	6.0	0.7 – 3.1
	Oct	-	2.0	1.6	0	8.7	0.7 – 4.0
E. Scotian Slope	Sep	-	1.7	1.5	0.4	5.8	0.5 – 3.4
	Oct	-	2.1	1.8	0.4	10.3	0.7 – 4.5
W. Scotian Slope	Sep	W	1.5	1.2	0.3	6.5	0.4 – 3.3
	Oct	W	1.9	1.7	0.3	8.3	0.6 – 4.0

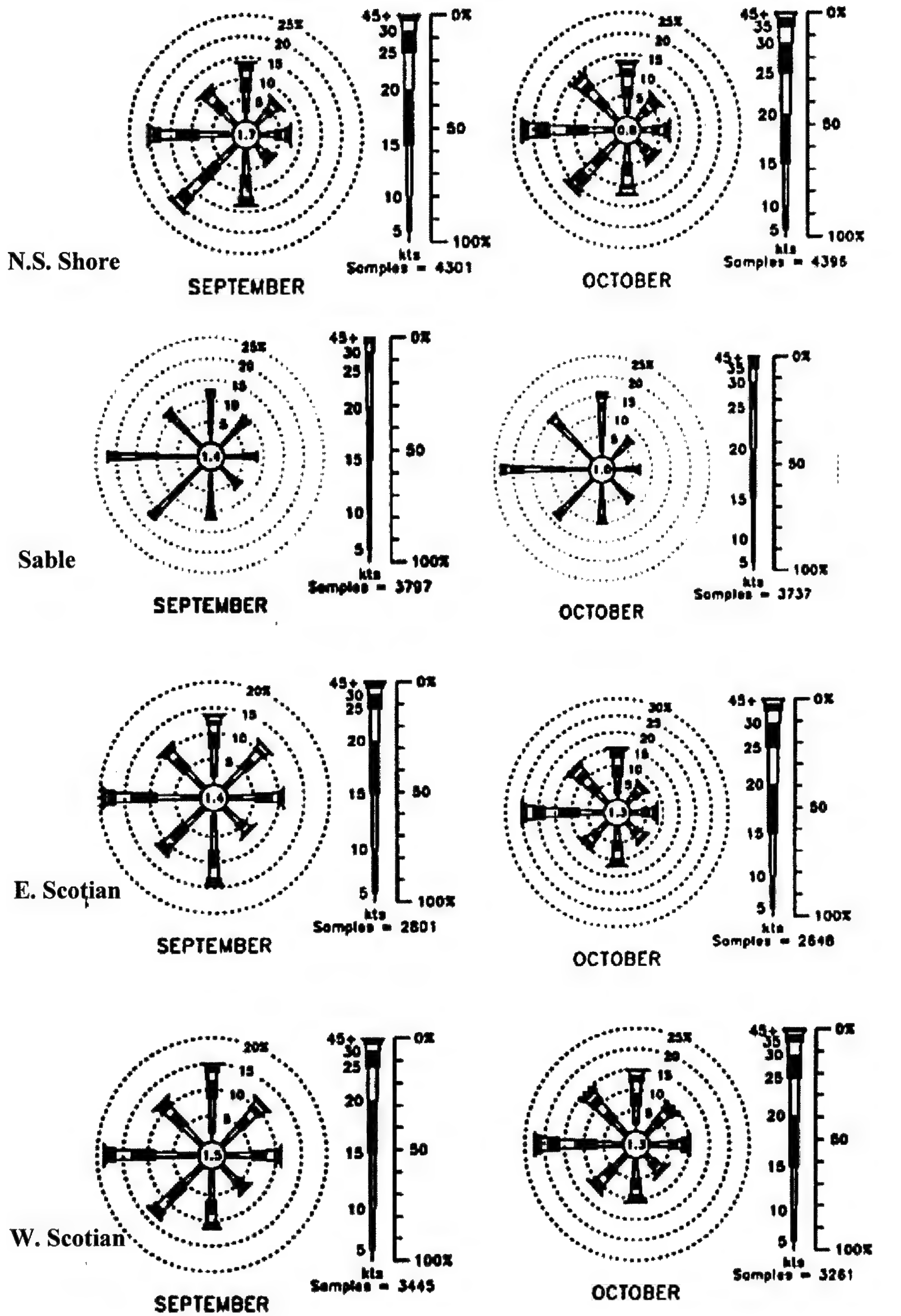

Fig. 20 — Frequency of wind speeds by direction for September and October (from http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Databases/WAVE/WAVE_e.htm)

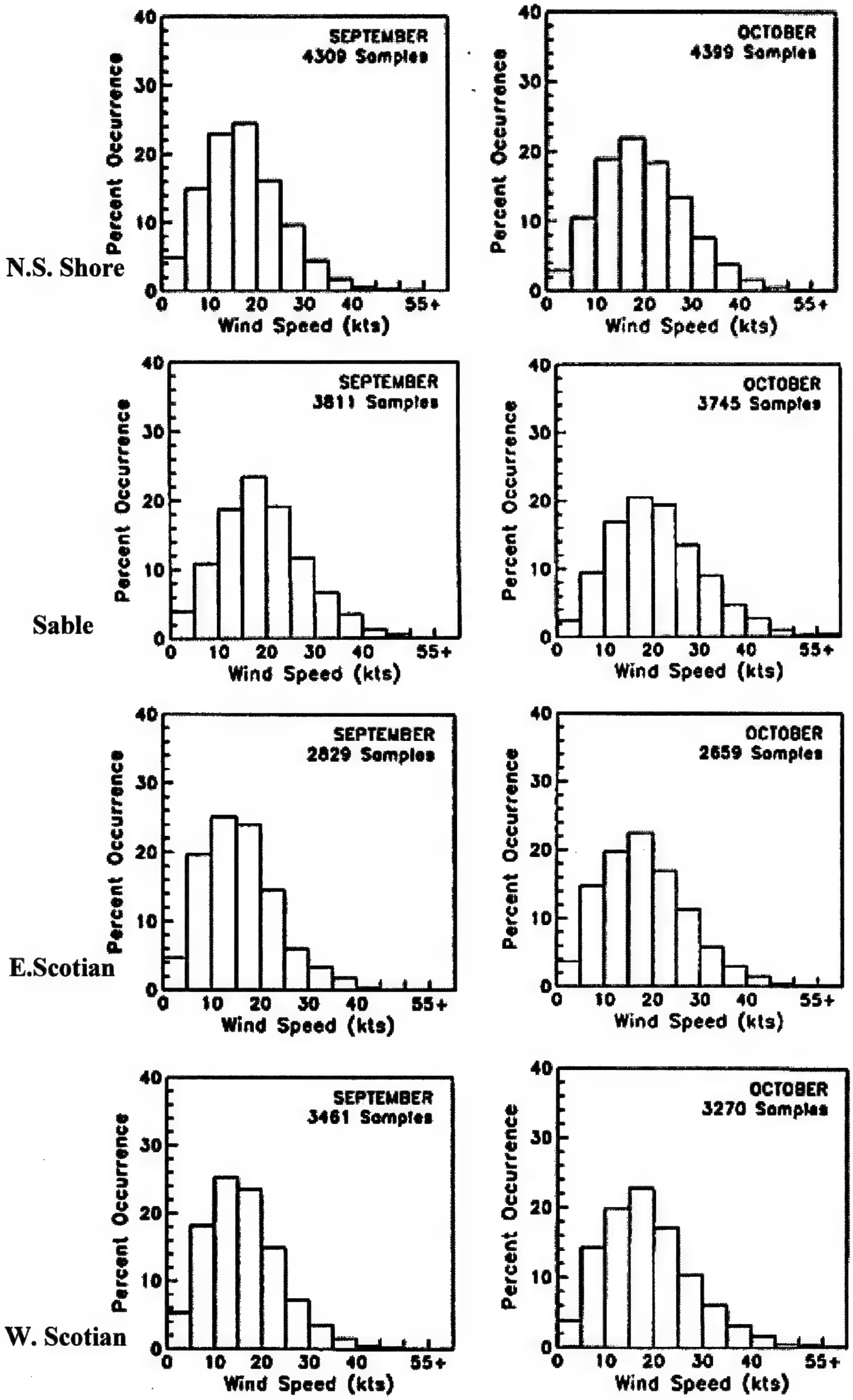

Fig. 21 — Histogram of wind speeds for September and October (from http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Databases/WAVE/WAVE_e.htm)

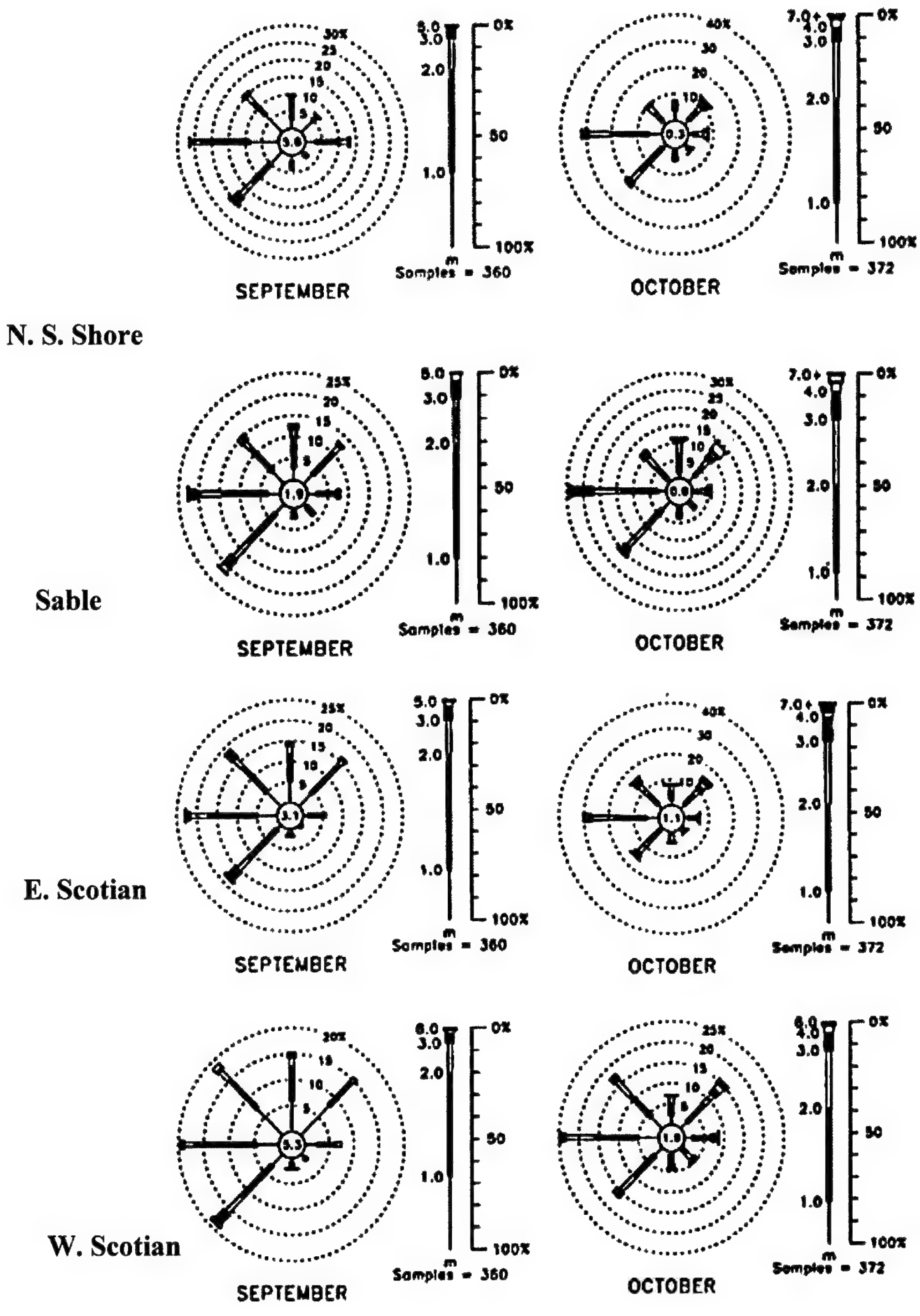

Fig. 22 — Frequency of significant wave heights by direction for September and October (from http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Databases/WAVE/WAVE_e.htm)

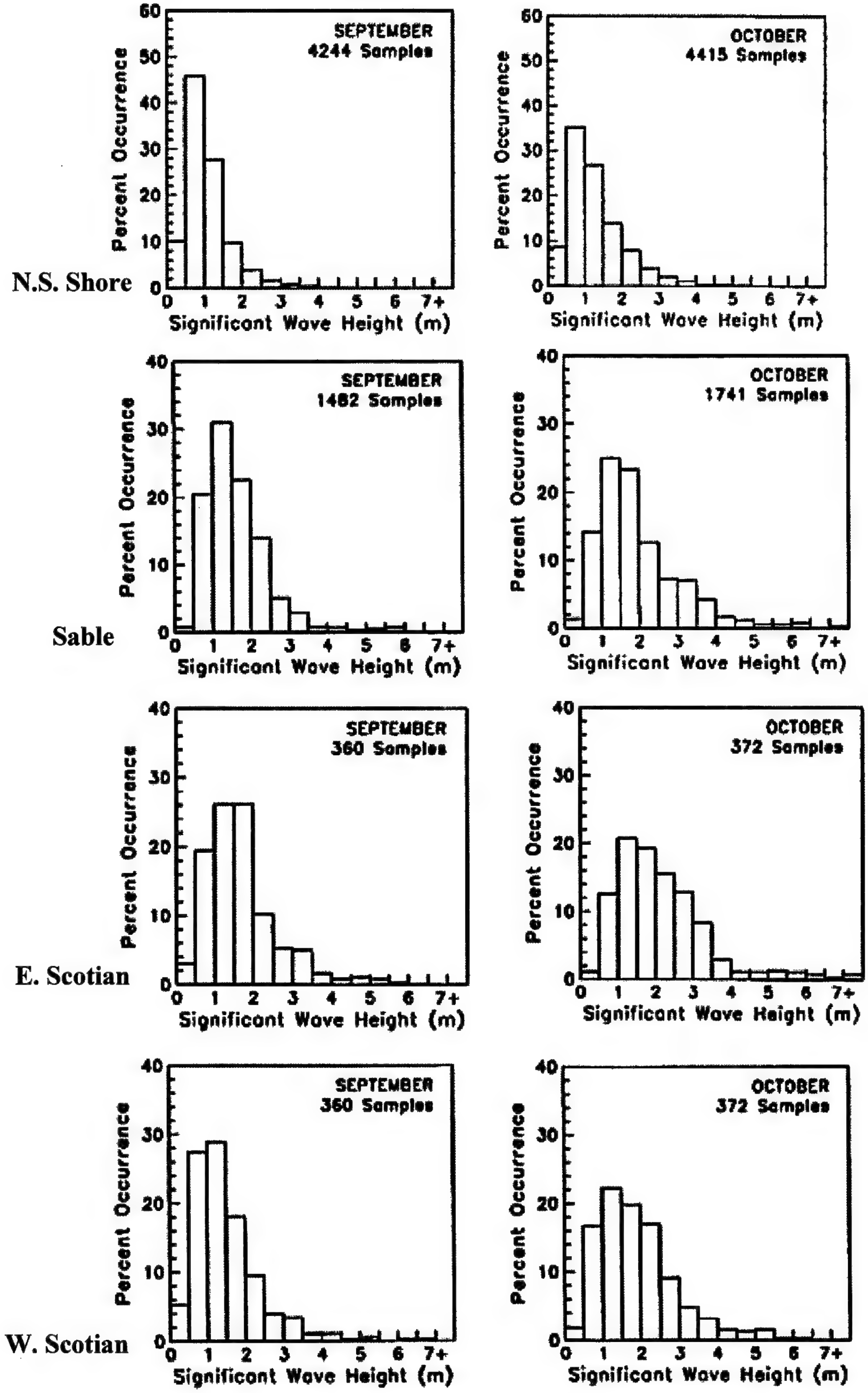

Fig. 23 — Histogram of significant wave heights for September and October (from http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Databases/WAVE/WAVE_e.htm)

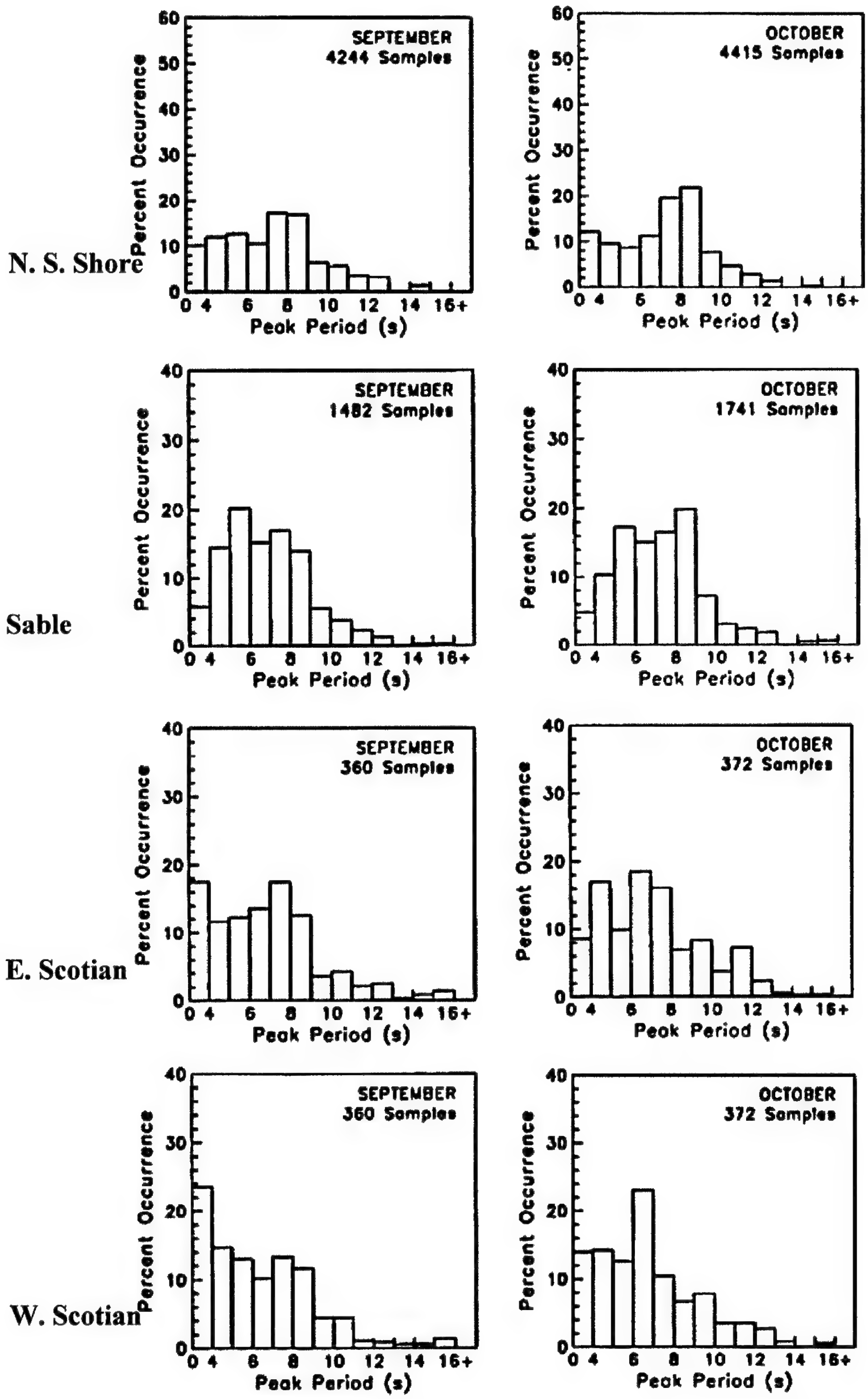

Fig. 24 — Histogram of wave peak periods for September and October (from http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Databases/WAVE/WAVE_e.htm)

6. SURFACE SHIPPING

Halifax Harbor is one of the largest natural harbors in the world with an entrance of approximately 2 km in width, stretching 8 km long into the inner harbor of the Bedford Basin. With no ice blockage, the harbor is accessible year round and is near major shipping lanes for the area. The harbor has a large influence on the Nova Scotian economy and in recent years has seen an increase in commercial traffic, especially container traffic.

Commercial traffic in the area is most concentrated near the Halifax Harbor and significant commercial and fishing traffic is expected to be present during the RDS-4 near-shore experiments. Commercial and fishing traffic are also likely to transit the Emerald Basin trial area. It should be noted, however, that long-liners (mainly swordfish fishing boats), usually in/near Emerald Basin in August, should be out of the zone by September. More information on fishing is found in the Maritime Provinces Fisheries Regulations found at http://www.ncr.dfo.ca/communic/policy/dnload_e.htm.

A study of vessel traffic patterns conducted in 2000 for Transport Canada shows that container vessels represented a large proportion of the Halifax traffic for that year. Vessels supporting offshore oil and gas activity are also prominent in the area. This study documented 1,215 vessels entering the Halifax Harbor area with 13% of them in ballast (http://www.fundyforum.com/pdfs/VslTraffic2000.pdf). Data for this study came from the Eastern Canada Region - Traffic Services (ECAREG-VTS) database.

Unfortunately, the most current shipping database is likely to be inadequate for pre-experiment predictions. Figure 25 contains a snapshot of ships distributed along shipping lanes in the North Atlantic near Nova Scotia. The model used to produce the figure is the Historical Vessel Motion Simulation (HVMS) model, which used the recently upgraded Historical Interim Shipping Database model (HITS 4.0). Two shipping lanes cross the area nearly parallel to the Nova Scotia shoreline. Ships traveling from the United States coastline into the Gulf of Lawrence comprise the near-shore lane that passes about 50 nmi from the Nova Scotia coast. Ships traveling in deeper waters toward the Grand Banks before turning northward comprise the second lane that passes about 80 to 100 nmi from the coast. HITS 4.0 is based on port records and lanes used in earlier versions of HITS and is lacking data from many ports. The fishing vessel estimates appear to be extremely low for the Halifax area.

7. LOCAL FISHING

In 1977, Canada established a 200-mile Exclusive Economic Zone that led to an increase in the local fishing industry. Commercial species of fish on the Scotian shelf include capelin, turbot, Atlantic halibut, white hake, silver hake, cod, haddock, and pollock, Atlantic herring, and Atlantic mackerel. A cod moratorium was implemented in 1993 after overfishing decimated the cod population and remains in effect (http://www.na.nmfs.gov/lme/text/lme8.htm).

Table 22 gives the metric ton distribution of Atlantic commercial fish landing for Nova Scotia in 2000. This and corresponding information beginning with the year 1990 can be found on the Canadian Department of Fisheries and Oceans web site (http://www.ncr.dfo.ca/communic/statistics/landings/land_e.htm).

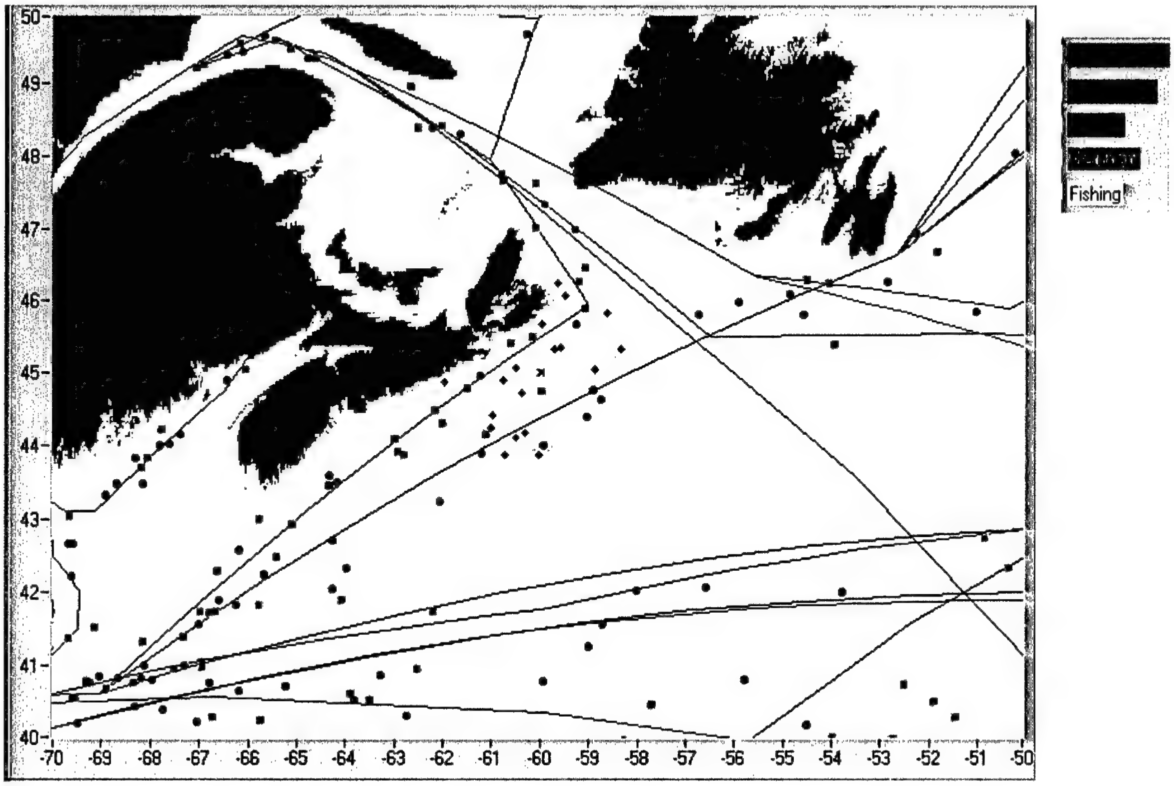

Fig. 25 — Single snapshot of ships distributed along North Atlantic shipping lanes. Ship types include super tankers, large tankers, tankers, merchants, and fishing vessels.

8. AMBIENT NOISE

Several studies have looked at the ambient noise levels on the Scotian Shelf (Hazen and Desharnais 1997; Piggott 1964; Zakarauskas et al. 1990). It is generally found that at frequencies where the noise field is mostly wind-generated (above ~200 Hz), the levels agree with those published by Piggott. Below 200 Hz, the levels at both sites should be high, corresponding to the heavy shipping traffic levels of Wenz (1962).

Table 23 reproduces ambient noise levels (based on approximate third-octave band averages) recorded at a site in the southern part of Emerald Basin, in 230-m water depth, on August 28-29, 2001. Four hours of data were used to produce these averages. The winds during the period were at 11.3 ± 2.4 kt (200°T), and the waves went down from 2 m to 1 m during the period. Periods of heavy rain showers produced the maxima shown in the last column of the table in Table 23. The mean levels (> 200 Hz) correspond to a sea state of 1 on the Piggott scale. Below 200 Hz, the levels correspond to heavy shipping traffic (following Wenz's curve).

Table 22 — Metric Ton Live Weight of Nova Scotia Commercial Fish Landings in 2000

	SEAFISHERIES	GULF	TOTAL
Groundfish			
Cod	8,251	1,197	9,448
Haddock	12,386	1	12,387
Redfish spp.	13.530	11	13,541
Halibut	701	13	714
Flatfishes	5,959	1,377	7,336
Greenland turbot	583	27	610
Pollock	5,674	2	5,676
Hake	14,927	111	15,038
Cusk	1,083	0	1,083
Catfish	189	1	190
Skate	479	0	479
Dogfish	2,364	44	2,408
Other	1,778	1	1,779
Total	67,904	2,784	70,688
Pelagic and Other Finfish			
Herring	71,589	5,575	77,164
Mackerel	4,020	306	4,326
Swordfish	741	0	741
Tuna	619	130	749
Alewife	78	275	353
Eel	0	5	5
Salmon	0	0	0
Smelt	2	12	14
Capelin	0	0	0
Other	1,002	19	1,021
Total	**78,051**	**6,321**	**84,372**

Table 23 — Measured Ambient Noise Levels in the Emerald Basin

Frequency (Hz)	Mean ($dB//1\mu Pa^2/Hz$)	Standard Deviation (dB)	Maxima ($dB//1\mu Pa^2/Hz$)
20	84.9	1.9	-
50	94.4	3.3	-
80	75.8	3.4	-
160	66.9	1.7	-
315	62.3	2.3	70.9
630	60.1	2.9	71.5
1260	56.6	3.4	70.8
2520	53.8	4.4	72.2

9. CONCLUSIONS

The Scotian Shelf presents a challenging area for acoustic experiments. While the region has been well studied, the geoacoustics are complex and the oceanography is highly variable. The site near the Halifax Harbor entrance provides maximum opportunities for target traffic near the RDS systems, but also presents difficulties in making pre-experiment acoustic predictions since the shipping patterns are unknown. There are some concerns with the potentially rocky seabed at this site and the way it could interfere with the deployment of arrays on the seabed itself, though sidescan surveys produced at the edge of the site suggest that the conditions should be acceptable if the systems are within 2 km of the shore.

The site located in Emerald Basin has been well characterized from both an acoustical and geophysical point of view. Again, the area is complex and presents a challenging environment for modeling. The water depth, on the order of 100 m, will allow for a wide range of deployment depths for the experimental systems. It will also allow potential submerged targets to conduct operations. Fishing activity is also more likely at this site.

10. ACKNOWLEDGMENTS

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